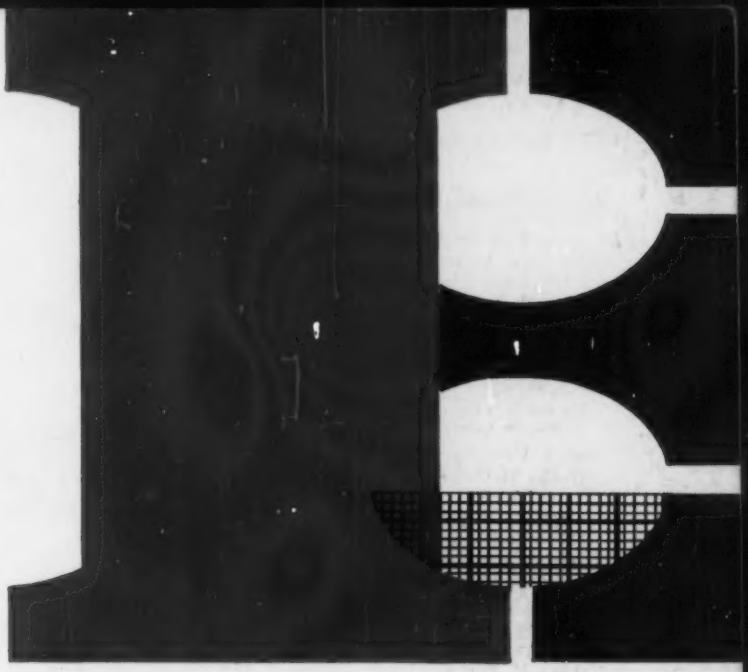

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New Approaches to Economic Comparison For Engineering Projects[1]

by J. MORLEY ENGLISH

Professor of Engineering and Director of Engineering Research, Department of Engineering, University of California, Los Angeles

THE investment decision problem is that of choosing one of a number of identified and relevant alternatives in order to maximize a prospective return to the investor. This implies that the investor must be able to specify the nature of the return or pay-off that he desires and, also, that he is willing and able to make some prediction of the future.

Traditionally, economy studies have implicitly assumed that the pay-off is money, discounted with respect to time at some constant rate (that is, interest). Predictions have been based on most likely outcomes in the judgment of the analyst, with only subjective and indirect evaluation of variance being taken into account. Current methodology has been focused on techniques of analysis in a deterministic sense. Such approaches as those characterized by Grant (2) and Terborgh (5), have been extremely useful, but perhaps by concentration on techniques of comparison, have detracted from consideration of the problem of the pay-off or utility-function and the prediction problem. It is the purpose of this presentation to raise questions concerning these two points, and, thereby, to dispute the validity of investment decisions reached by traditional methods of analysis.

THE UTILITY-FUNCTION

A decision to invest in one alternative in preference to some other is based on judging which offers the greater expected pay-off or return, in terms of some utility-function or personalized value system. The utility-function, whether that of an individual or of a corporation, is an extremely complex thing. It includes many components which are nonmonetary and highly subjective. It is not constant with time. Fortunately, in comparing any two alternatives (or a set of alternatives in pairs) any elements which are identically equal for both can be excluded. Thus, we need only to identify the elements of costs, incomes, etc., which are different. Certainly, many components will remain subjective and not readily analyzable. This means that they will always represent an important area of judgment. The components, which are related to the comparison and which we will consider, are:

1. The utility of time (time-value of money).
2. Length of time of the investment commitment.
3. Utility associated with risk.

The discussion of the last of these is deferred until after the discussion of prediction.

The time-utility of money reflects in some form a discounting of the future. Simply stated, it is: "A dollar now is worth more than the promise of a dollar at some future time." Traditional treatment in economy studies introduces this concept as the "time-value" of money, and compares alternatives in terms of a constant rate (interest or rate-of-return) at which the future is discounted to the present (2). This has been accepted as an axiom whenever the rate-of-return approach to comparative economic studies has been employed. Since so much of the financial structure of business is predicated on this, such a constant rate tends to truly reflect a time-value concept. However, I contend in this presentation, that it may lead to error in reasoning; the rate at which an individual discounts the future need not be constant. The notion of a time-value reflects the money market situation, whereas a time-utility notion is the personalized evaluation of money with respect to time. It is intuitively correct for the individual to discount the future completely beyond some arbitrary point in time. For example, a man who has been given two more years to live, barring his concern for relatives, will be inclined to discount a dollar return for the third and subsequent years at an infinite rate; he will have no utility for any return after two years.

In replacement economy, the pay-out period policies for determining when a replacement is economical is considered to be erroneous by those who have consistently used a constant rate in economy studies. However, let us consider what this means in terms of utility. If we plot the interest rate, r, as a function of time (Figure 1), we see that both the policy of "paying for itself in T_1 years" (Curve A), and the constant rate (Curve B), are straight lines. The "pay-out" period approach, in

[1] Based upon a presentation to the American Institute of Industrial Engineers Conference in Detroit, Michigan, on May 12, 1961.

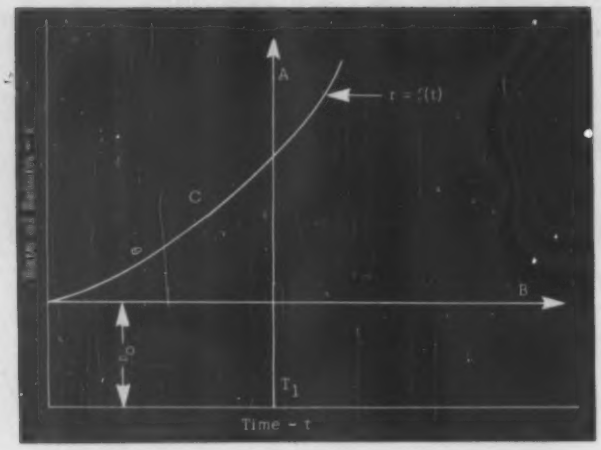

FIGURE 1

effect, says we will not discount the value of any dollar, $r = o$, in time $o \leqslant t \leqslant T_1$ and will fully discount it, $r = \infty$ in time $t > T_1$. Neither of these idealizations is a true representation of actual utilities. Depending on the degree to which the present time features more strongly than the future in one's utility-function, we will tend toward one or the other of these idealized curves. A realistic rate of discounting of the future may be represented by some function of time (Curve C), which is not discontinuous. On the other hand, it is not a function which may be determined either analytically or experimentally. Since this is subjective, it is suggested that any convenient function may be used and reference points on the curve may be established arbitrarily. These may be the initial rate r_0 and an arbitrary future which approximates the extreme range of your interest of the future. Thus, such a convenient function is

$$r = r_0 \sec \frac{\pi}{2} \frac{t}{T_0} \qquad \text{Eq. 1.}$$

Another convenient function which alternatively might satisfy such a criterion is the exponential form

$$r = r_0 e^{at} \qquad \text{Eq. 2.}$$

When $a = o$ the function reduces to the conventional constant interest r. The company which must place a high utility on present dollars (that is, one concerned with questions of cash flow), will tend to establish a high rate of discounting dollars in T_1 years, say $r = r_1$.

Then,

$$r = r_0 e^{t/T_1 \operatorname{Log} r_1/r_0} \qquad \text{Eq. 3.}$$

Example—Assume the planning horizon of company *xyz* is 10 years. The base interest, on which they choose to make investment decisions, is 10%. However, the policy concerning the long range future is that 100% rate in the 10th year is needed to justify an investment.

From Eq. 3.

$$r = 0.10e^{0.23t}$$

The advantages of the proposed method include an intuitive appeal that immediately provides a way to reconcile the short-run and long-run viewpoints. It is interesting to note that such companies as the telephone company have adopted a constant rate-of-return approach in all of their economy studies, whereas smaller and newer concerns lean toward a limited pay-off approach.

The managements of both large established and small new concerns have intuitively reflected the philosophy of their respective time-utility functions. The management of the telephone company is planning beyond the life of its personnel, whereas the manager of the small company often is identifying the company goals with his own goals. On the other hand, there are situations in which the divisions of a telephone company should be concerned primarily with the short range return, and vice-versa for the smaller company. The proposed new approach forces consideration of the nature of the utility-function. It places judgment on a level which is closer to experience. It leads to the conclusion that the one alternative will be chosen by one company and the second by another company. This is consistent with observation.

Adoption of this proposed, more general rate-of-discounting requires a revised analysis. The costs (and incomes) associated with a proposed project are a function of time, $x(t)$, which will contain both discrete and continuous elements (for example an initial investment I plus an annual cost R). Thus, the weighted present worth, in its most general form is:

$$P = \int_0^T x(t)e^{-r(t)t}dt \qquad \text{Eq. 4.}$$

This present worth may be converted to an equivalent uniform annual cost associated with the project in a similar manner to the "Capital Recovery Factor" used by Grant. The present worths neglect the elements of costs for the interval between their life expectancies and, therefore, an equivalent annual cost is needed

$$P = \int_0^T x(t)e^{-r(t)t}dt = \int_0^T Re^{-r(t)t}dt$$

where R is an equivalent uniform rate of cost. Thus

$$R = \frac{\int_0^T x(t)e^{-r(t)t}dt}{\int_0^T e^{-r(t)t}dt} \qquad \text{Eq. 5.}$$

It should be recalled that in an equivalent annual cost approach, the identical project is assumed to be repeated for an indefinite number of times. However, other factors should enter into our consideration.

The alternative with the shorter expected life provides an opportunity to the decision maker to reassess his position, and to make a new or repeat decision in the light of experience, new information, and improved alternatives, as well as to reassess his utility-function. Therefore, in this respect there is a distinct advantage to

the shorter-lived alternative. In traditional approaches this has been disregarded except for the one case of the replacement economy problem. Terborgh in the development of the MAPI replacement formula (5) allows for technological change, by assessing an increasing cost function against the "challenger," (the project which challenges the replacement of an existing installation). This same approach is valid for the comparison of two new alternatives, but its importance as a factor in the decision, diminishes as the expected lives of the alternatives approach one another. For the replacement situation the alternatives usually reduce the retention of the "defender" for a limited period versus a considerably longer-lived challenger. A number of approaches to the treatment of the advantage of a new decision at the end of the shorter life expectancy may be developed. One of these might be to make an assessment of the cost of the decision and of a weighted dollar utility associated with the advantage of the opportunity to make the earlier decision. The costs are then reduced to some basis of equivalent utility for comparison just as for any other element of the cost function.

PREDICTION

The predicted costs of a project are based on the information of past experience. If certain assumptions as to the relationships of the parameters of the statistical data can be made, then it may be possible to extrapolate some regression function into the future. Of course, it must be recognized that the future outcomes may be greatly influenced by factors which were relatively insignificant in the original data and, hence, do not reflect in the regression function. This is obviously the major pitfall in any prediction. Furthermore, many predictions must be made on subjective and intuitive information. Nevertheless, conceptually, it may be permissible to represent a prediction as an extrapolation (Figure 2). If the regression function is of a form $y = ax + b$, it will be observed that a and b as the intercept and slope of the regression function will be random variables whose means establish the prediction function. The variances of a and b indicate the way the variance of the prediction curve will tend to increase as a function of time. This means that the confidence of an estimate diminishes the further into the future one makes it. A means of accounting for this tendency in economic comparison has been suggested by English and Haase (1). The method proposed involves the development of a present worth in terms of a projection function whose variance is determined by the variance of $x(t)$. The variance of $x(t)$, σ_x^2 is assumed to be an exponential function of time.

Stated in its general form, alternative investments can be compared by some function of expected equivalent annual cost and variance of annual cost. Using the more general concept of rate-of-discounting developed earlier

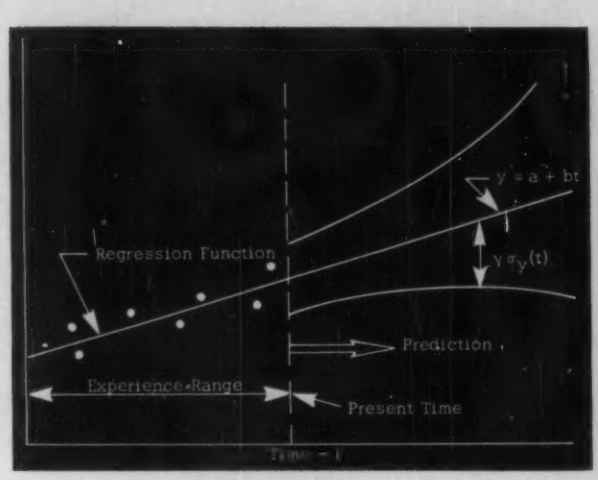

FIGURE 2

the present worth is

$$P_1 = \int_0^T \{E(x) - w\sigma_x(t)\} e^{-rt} dt \qquad \text{Eq. 6.}$$

If we use Curve A which might be chosen arbitrarily

$$P_1 = E(P) - w \int_0^T \sigma_x(t) e^{-rt} dt \qquad \text{Eq. 7.}$$

The function used for comparison of alternatives is modified then to

$$f(R) = \frac{\int_0^T E(x) e^{-rt} dt - w \int_0^T \sigma_x(t) e^{-rt} dt}{\int_0^T e^{-rt} dt} \qquad \text{Eq. 8.}$$

In effect, this introduces an expectation-variance principle of choice as discussed by Morris (3). The factor w which makes is possible to make a probability statement about P_1, may be considered as a weighting factor for the influence of variance.

UTILITY ASSOCIATED WITH RISK

As yet, we have not discussed how one might go about selecting the weighting factor, w, for the influence of variance on the decision. This is extricably related to the utility-function and as a consequence must remain largely subjective. However, it is well to reflect on the nature of the interaction between the utility-function and variance of the outcome.

If the utility-function is a straight line and one plays the game with a finite investment from an infinite capital resource then, according to the laws of large numbers, variance should not enter into the consideration of any single investment. This would also be true if we play with a large part of our capital provided that we could truly say that the utility-function is linear, that is, the concept of marginal utility of money does not enter into the problem. By limiting the amount of any one invest-

ment to a small fraction of the total capital, one effectively limits the probability interval to a sufficiently small region of the utility-function, which for all practical considerations, may be considered a straight line. Thus, for small commitments, expectation alone should be the criterion. On the other hand, when a larger proportion of capital is risked, the greater will be the effect of variance. How this may be done will depend on a definition of a utility-function. It is sufficient for purposes of this article merely to call attention to the principles involved.

If the investment, I, is considered to represent the costs associated with some initial period, t_i, during which the project is initiated, it may be represented in a formal way as

$$I = \int_0^{t_i} x(t)e^{-rt}dt \qquad \text{Eq. 9.}$$

Then the weighting factor for the influence of variance on the investment decision may be subjectively determined as a function of I

$$w = w(I) \qquad \text{Eq. 10.}$$

THE INVESTMENT DECISION

The foregoing considerations may all be incorporated in the generalized statement that alternative projects are compared by ranking some equivalent annual utility parameter $f_i(R)$. These may be equated in pairs

$$f(R)_A = f(R)_B \qquad \text{Eq. 11.}$$

Due to the complexities of solution of Eq. 11., it will be easier to assign a value for a reference or base rate-of-return, r_o and rank the alternatives in terms of r_o. This is precisely what is involved in the traditional present worth and capital recovery comparison techniques. Thus, given an r_o, the project with highest $f(R)$ will determine the choice of project. It should be emphasized that by introducing the weighting factor, w, into the equation, and by involving a functional relationship for discounting of the future, the rate-of-return r_o does not retain its usual meaning. In a sense it may be thought of as a base rate-of-return or perhaps more appealingly it might be called a "Profitability Index."

CONCLUSIONS

The foregoing development may appear to introduce added complexity into the method of analysis of investment alternatives. There is always a danger that a complex calculation presents an appearance of precision and accuracy which indeed is not justified by the subjective judgments which cannot be included in the numerical analysis but which are essential to sound conclusions. It is claimed that the added complexity of the proposed approach is justified by the necessity to focus on the assessment of the utility-function of the company. The traditional approaches used in economy studies, insofar as they may ignore these considerations may tend to lead to erroneous conclusions. In the traditional approach, the subjective evaluations are introduced in the comparison of the computed equivalent annual cost, where the effect of experience is more remote.

The proposed method provides a means of taking into account a varying rate-of-discounting of future monies, a utility associated with the opportunity to reconsider a decision at the earlier time, and a weighting of the size of the capital commitment. These elements all involve judgment but are introduced consciously at a meaningful level of experience. The result should be improved investment decisions.

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CONTRIBUTED TECHNICAL PAPERS FOR THE THIRTEENTH ANNUAL NATIONAL CONFERENCE

Sessions at the Annual National Conference of the American Institute of Industrial Engineers, to be held in Atlantic City on May 17 and 18, 1962, will be open for contributed papers by individuals doing research or development in the area.

Titles and abstracts of these papers must reach Andrew Schultz, Jr., Upson Hall, Cornell University, Ithaca, New York, by March 15, 1962. The title should include: title of paper, full name and initial of the author, his affiliation and address. The abstract should be carefully prepared to indicate the essence of the paper, the purpose, what was done, and the conclusion; and it should be limited to two hundred words, double spaced, with one carbon.

It is hoped that the membership will take advantage of this opportunity to report on research accomplishments.

Operating Systems Control by Use of Prime Paper[1]

by HERBERT E. POUND

Systems Analyst, Procedures, Aero-Space Division, The Boeing Company

COMPANIES have means for controlling operating costs attributed to manpower, material and facilities, but by what means do they control costs attributed to faulty implementation of their operating systems? Let's try to find out by taking a look at a typical company.

We find that, because of "span of management" limitations and the fact that the activities are naturally grouped into functional categories, the company consists of a few primary departments and several complementary departments.

We also note that this need to push down authority and responsibility has resulted in a collection of autonomous authorities—all of whom are sincere about accomplishing their own activity objective. The initial company-wide operating system is the result of the thinking and personality strengths of these managers. The quality of the system depends upon the degree of uniform cooperation between these managers and their intelligent application and analysis of flow chart principles.

When unforeseen or new ideas are brought into the system the locally affected managers are the ones who accomplish the change. It seems to be par for the course that they take the approach of, "Let's try this new idea out, and if it's any good, we'll adopt and document it." This is often done without the benefit of flow charting or consideration of the indirect effects on other departments of the overall organization. In fact, the idea is often adopted without any knowledge that it may create a new situation (havoc) in another part of the company.

To add to the confusion, we find that the organization faced with the new situation works out a procedure to handle it—again without knowing the consequences on other departments. The fact that each of these problems is worked out and procedurally documented locally does not insure that the basic operating system remains under control at all.

Each activity has an index or filing system for procedures in its manuals which may or may not follow the company universal numbering or functional category system. In any case, the system does not offer any real method of control for it is merely a convenient filing system that is related only to the company structural setup, rather than to the operational system. In fact, one reason the situations previously mentioned occur, is that it is often difficult for a manager faced with a new situation to locate a procedure on a subject.

The index is, however, the place to establish control of the operating system, for it is the only point where it can be totally documented. This paper proposes a method by which this may be done.

ACTIVITY—PAPERWORK RELATIONSHIP

First we will recognize a basic fact—overt behavior is usually recorded on a corresponding piece of paper. We ourselves "are not" unless we can be identified on paper as being what we are—married, a specialist, auto or home owner, or even born. Usually, nothing "happens" until a piece of paper is filled out. You don't get to take your bride home until the certificate is signed. A boxing match does not happen until papers are signed. Likewise, a business does not exist or start in motion without paper. Although a production manager may think he is putting parts together to build a product he must realize that these parts and the paper that represents them are in essence the same thing. He, then, is really interested in putting together a component and its corresponding complete set of paper.

It is suggested that for each major activity there is usually one single prime piece of paper (form) which must be moved through the organization to accomplish the activity objective. Practically every other piece of paper and procedure in the activity can be presumed to take on certain relationships to the prime paper as ascertained by the fact that they will start, move or follow it up through completion. These relationships may generally be classed as authorizations, preparation, release and follow-up.

The problem of determining where these prime pieces of paper exist, so that the index will be located at the proper level, is the one which we will now consider. Our analysis will be made by starting at the top of the company organization chart and establishing a control point in each office which is responsible for the one prime piece

[1] An entry in the Annual Professional Paper Contest sponsored by Seattle Chapter, American Institute of Industrial Engineers.

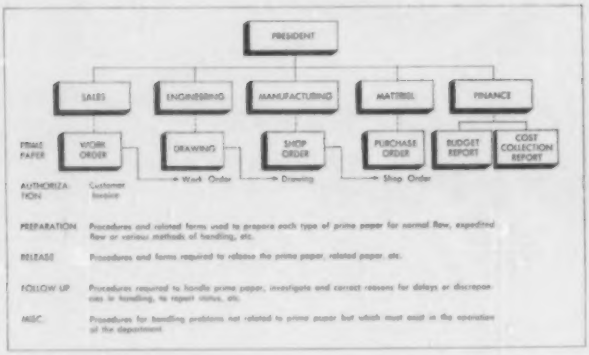
PRESIDENT
SALES
ENGINEERING
MANUFACTURING
MATERIEL
FINANCE
PRIME PAPER
WORK ORDER
DRAWING
SHOP ORDER
PURCHASE ORDER
BUDGET REPORT
COST COLLECTION REPORT
AUTHORIZATION
Customer Invoice
→ Work Order
→ Drawing
→ Shop Order
PREPARATION
Procedures and related forms used to prepare each type of prime paper for normal flow, expedited flow or various methods of handling, etc.
RELEASE
Procedures and forms required to release the prime paper, related paper, etc.
FOLLOW UP
Procedures required to handle prime paper, investigate and correct reasons for delays or discrepancies in handling, to report status, etc.
MISC.
Procedures for handling problems not related to prime paper but which must exist in the operation of the department

FIGURE 1. Basic Organization Structure—Including Relationship of Basic Operating System by Prime Paper.

of paper which must be processed through its organization to accomplish the activity objective. We notice that, aside from the necessity of insuring that the enterprise objective is maintained, the managers have been free to choose any type of organizational structure which they believe will best accomplish their individual objectives, that is, functional, territorial, product, customer, process or a combination of these. This will not hinder our search for prime paper, however, for the type of structure does not alter this approach to control.

It also really doesn't matter what type of company we are studying—service, product or manufacturing. For purposes of simplicity we'll assume that ours is a manufacturing company. It contains five primary departments, Sales, Engineering, Production, Materiel and Finance. The company-wide operating system is dependent upon the relationships between these departments.

There is no one single piece of paper in the operating system to control these relationships, but a little effort brings forth the fact that there usually is a single prime piece of paper for each of the departments.

For example, the work order, drawing with parts list, production order and purchase order can be considered as prime paper for their respective Sales, Engineering, Manufacturing and Materiel Departments. The Finance Department, having more than one activity function, may have several prime pieces of paper which can be controlled. The company organization chart might look like that shown in Figure 1.

CONTROL LEVELS

The department level then appears to be the ideal place to place our controls. This is the level where coordination of "what" each department promises to do for each other to establish and maintain the system exists. Control of changes to the system is in the hands of a few department heads whose familiarity with the enterprise objective is clear.

It is also the level which can best control the individual department operating system as it relates to the prime piece of paper. The bulk of the company procedures are, of course, written at this level. Consequently controls here are of the utmost importance.

Once this prime piece of paper is identified, it becomes reasonably simple to proceed in the investigation of the system that is used to move it through the respective activity department. Let's remember that we are searching for every form or procedure used in the system and that these will be placed in their proper classification in the index—authorization, preparation, release, follow-up and miscellaneous. Our work sheet may look like Figure 2. We notice for example, that it contains:

1. A list of forms used by classification.
2. A list of documented procedures by classification.
3. A ready identification of relationships of forms and procedures to the prime paper.
4. A complete picture of the activity objective.

A formal index might be proposed as illustrated in Figures 3 and 4. This index now becomes a tool which is located at the responsible level and which can be easily used by all concerned persons.

Things to be considered before any thought is given regarding how to use this tool, is "what is to be controlled?", "to whom is the control applicable?", and "who is to be responsible for the control?".

As previously indicated, the established operating system should always be what the responsible manager believes it to be. Any change in either procedures or forms must be evaluated with the system in mind before being approved.

CONTROL RESPONSIBILITY

The line managements responsible for segments of the system are the ones "to whom the controls are applicable," for it is they who attempt to make changes for a variety of reasons. Desire for new forms, undocumented emergency conditions, desire to implement or experiment with a new method, etc., are some reasons for these attempts. Requests may also come from line management in other activities.

The manager of the activity, who is responsible for completion of the objective, naturally, should assure that

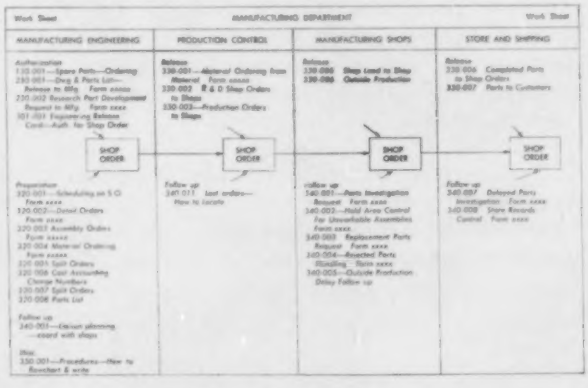

FIGURE 2. Work Sheet.

The first three digits will identify the department and classification of the procedure as related to the prime paper.

The last three digits are the assigned number given the procedure in its respective classification as it is developed.

Dept.	Prime Paper	Basic Identification Number	Classification Identification Number				
			Authorization	Preparation	Release	Follow-up	Misc.
Sales	Work Order	100	110	120	130	140	145
Engr.	Drawing and Parts List	200	210	220	230	240	245
Prod.	Shop Order	300	310	320	330	340	345
Materiel	Purchase Order	400	410	420	430	440	445
Finance	Payroll	500	510	520	530	540	545
	Financial Statement		560	570	580	590	595

FIGURE 3. Procedures and Forms Index—Preface.

this control is located either in or responsible to his office. The emphasis from this office which is put on the need for controls will determine the success or failure of the project.

A word of caution is mentioned here, for the reader should not get the idea that the word "control" means "delay." This paper will assume that the procedure system has a built in method for rapid revisions by line management and that it has the backing and cooperation of all affected managers.

The grouping of procedures by the suggested classification readily shows the index to be a control tool which can be used by all concerned. Every piece of paper (procedures and forms) has been collected in a usable manner. Although it may appear that we should investigate

Procedure Number	Title	Form	Title	Auth	Prep	Rel	F/U
Manufacturing Department—Prime Paper—Shop Order							
230-001	Drawing and Parts List—Release to Mfg.	xxxx	Engineering Release Part Card	X			
230-002	Research Part Development—Request to Mfg.	xxxx	Development Manufacturing Req.	X			
310-001	Engr. Release Part Card—Auth. for Shop Order	xxxx		X			
320-001	How to Schedule	xxxx	Master Schedule		X		
320-002	Detail Orders—Preparation	xxxx	Shop Order		X		
320-003	Assembly Order—Preparation	xxxx			X		
320-004	Ordering Material for	xxxx	Material Order Card		X		
330-001	Material Order Card—Release to Materiel	xxxx				X	
330-003	Release to Shops	xxxx				X	
340-001	Parts Shortage Notification	xxxx	Store Out of Stock				X
Materiel Department—Prime Paper—Purchase Order							
230-001	Drawing and Parts List—Release to Mfg.	xxxx	Engineering Release Part Card				X
330-005	Material Order Card—Release to Materiel	xxxx	Material Order Card	X			
410-001	Material Order Card—Authorization for P.O.	xxxx	Material Order Card	X			
420-001	Selection of Vendors	xxxx	Vendor Selection Form		X		
420-002	Preparation—Outside Production	xxxx	Blanket Purchase Order		X		
420-003	Preparation—Normal Order	xxxx	Purchase Order		X		
430-001	Release to Vendors	xxxx				X	
440-001	Follow-Up on Vendors	xxxx	Request for Information				X

FIGURE 4. Procedures and Forms Index.

procedures and their related forms simultaneously, we find that our analysis may indicate that an investigation should start on a form in one instance and on a procedure in another. For this reason we will consider them separately.

FORMS AND PROCEDURES ANALYSIS

We will discuss forms first, for it is easier to spot duplication of use of a form in any of the classifications. Control of forms may be accomplished by evaluating them as follows:

1. Repetitive listing of a single form in any one classification may indicate duplication of procedure coverage.
2. An accumulation of a number of forms under a single classification is usually cause for an investigation into the need for so many forms. A reduction in the number of forms and related procedures is often possible, by combining forms which contain similar requirements. This may or may not improve the operating system, but certainly reduces costs.
3. Duplication of forms may be avoided. All attempts or requests by the line supervision for new forms can be checked against the index to determine if there may already be one in existence which can handle the problem.
4. Requests for a change in a form often affect the existing procedure (operating plan). This must be evaluated in total to insure that the basic plan is not aborted.
5. A variety of forms received from other organizations may be noticed which authorize the preparation of the prime paper. When this causes a number of procedures to exist in the organization solely for the purpose of handling them, a review might be made to consider the possibility of developing a single form which all outside organizations would be required to use.

Procedures listed in their proper classification may be controlled and evaluated much like the way we handled forms.

1. Too many procedures under a single classification can indicate that like organizations are doing the same thing differently. An investigation can determine the most effective procedure and steps can be taken to get it adopted by all of them.
2. Chances for duplication of procedures are reduced when they are classified in a manner which makes it easy to locate a procedure on a needed subject.
3. Requests for a change in any part of the system can be evaluated for its effect on the overall system because the applicable procedures in the related classification are easily found.
4. Control of relationships between departments is easily obtained. It is logical that a "release" procedure in one department, for example, might be an "authorization" in another.

The foregoing are examples of methods for using the index to control the operating system. However, in addition to the direct means of control secured by classification in relationship to a prime piece of paper, there are other indirect benefits that may be had with very little extra effort.

UNIFICATION OF PURPOSE

Our attention so far has been concentrated largely on the mechanics for developing an index as a control. We should now step back a bit and see what the prime piece of paper can do in a more general way.

Let's twist the word "control" we've been using to "unification of purpose" and see if more advantages become apparent.

The question we had to ask to locate the prime piece of paper was, "What piece of paper is important to the entire organization?" Once located, we realized that the converse thought also held true—that the entire organization (people, procedures and forms) must have a "unification of purpose" toward this prime piece of paper.

We have, then, an opportunity to do what every manager prays for—keep everyone pointed in the one direction of accomplishing the activity objective. The classification system used in the index forces thinking in this direction. Additionally, we can further utilize this opportunity with no extra cost by merely "slanting" the procedures toward the prime piece of paper.

Instead of titling procedures to form names or with passive titles and purposes, they can be slanted toward the prime paper. For example, let's take a form—we'll call it an Emergency Parts Release (EPR). Its purpose is to get an extra part from a store to replace a part which a manufacturing shop has damaged. The normal "purpose" stated in procedures describing the use of the form is "to develop a method to process an EPR." A slanted purpose might read "to establish an emergency method for obtaining replacement of damaged parts to permit resumption of production on a shop order." The reference to the need to resume stopped production on the prime paper, the shop order, gives weight to the purpose and makes the user aware of the activity objective.

This technique of slanting is very instrumental in establishing a uniform purpose in all effort. It naturally has a morale boosting effect on personnel which is in itself a control, for when there is a singleness of purpose any deviations are more apt to be noticed and questioned.

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Pacing Effects in Production Lines

by **ELWOOD S. BUFFA**[1]

Associate Professor of Production Management, School of Business Administration, University of California

PERHAPS we have all heard accounts of labor disputes that erupted because a foreman allegedly tampered with the speed control of the conveyor. If he wanted extra output, should he have speeded it up or slowed it down? What functions do banks between operations perform?

These questions are interrelated and fortunately, recent research gives some information about them. In a series of experiments dealing with work paced by a conveyor or a machine, Conrad (2) compared the output results for the same task when the operator was rigidly paced so that parts could go by the operator unprocessed, when the queues were allowed to build up, as well as other important conditions. Rigid pacing means that parts are rigidly attached to conveyors. Results of these experiments showed that the critical determinant of output was the time that the part was available to the operator. Thus, when the operator was rigidly paced, the time available was minimized, and so was productivity. When time available was maximum, the net output was also maximum.

The explanation for Conrad's results is straight forward. The operator's performance time is not a fixed number, but is represented by a distribution. If the operator happened to be occupied with one of his longer cycles (perhaps because of some minor difficulty in the fit of parts, a fumble, etc.) the unit might by-pass him unprocessed, thus, reducing output below line capacity. On the other hand, when queues of parts were allowed to build up, full line capacity was realized in Conrad's experiment. The clear logic of the reason is that the operator could counter-balance his long cycles with his shorter cycles, so that his average output rate could match that of the conveyor or machine. The parts would not pass him by, but wait for him.

Hunt (3) examined the same type of situation from a theoretical viewpoint, using a waiting line model. He assumed Poisson arrivals and service rates, calculating the maximum possible utilization of the line and average banks for different cases of banking limitations and different numbers of stages or stations. Table 1 shows Hunt's maximum utilization figures for a two-station balanced line. Note that it is only in Case 1 where infinite queues are allowed in front of each station, that full utilization is possible. In Case 2, which corresponds to Conrad's rigid pacing, utilization falls to its lowest level. For Case 3, with five different levels of finite queues beteen stations, we can see the continuous improvement in the maximum utilization factor as the allowable bank increases. This agrees with Conrad's conclusion that the time that the part is available to the operator is critical.

Translating these ideas into design criteria, lines should be designed so that the parts are available as long as possible to operators in order that they can average out the long cycles against the short cycles in their work time distributions. This means the provision for banks between operations rather than to attach parts rigidly to conveyors in order to achieve maximum or near maximum utilization.

One might raise the question, "Parts are often rigidly attached to conveyors in industry, and it doesn't seem as though parts are going by unprocessed; how do they get away with it?" One answer is that they get away with it by under-utilizing everyone on the line so that the probability that a part will get by unprocessed is quite small. This, in combination with a physical layout that extends the time available, may result in an acceptable design. If parts must be attached rigidly to conveyors for some reason, then the system should be designed so that parts are available to operators for the maximum period of time. Thus, for large assemblies, like automobiles, refrigerators, washing machines, etc., the system is often designed so that workers ride the conveyor while performing their portion of assembly, or walk along with the part as it moves. This tends to allow the needed flexibility.

For smaller parts where the worker may be restricted to a work place, time available depends upon belt speed and parts spacing on the conveyor, for the same frequency of feed. Figure 1 shows this effect for a work place on a line where the worker is seated and can reach

TABLE 1

Calculated Values of ρ_{max}, the Maximum Possible Utilization for a Two-Station Line and the Indicated Banking Limitations (3).

Banking limitation		ρ_{max}
1. Infinite queues allowed in front of each station		1.0
2. Infinite queue allowed in front of first station. No queues allowed for other stations.		0.6667
3. Infinite queue allowed in front of first station, the following finite queues allowed in front of other stations:		
	$q = 2$	0.75
	$q = 3$	0.80
	$q = 4$	0.8333
	$q = 8$	0.90
	$q = 18$	0.95

[1] The author is indebted to David A. MacDonald, now with Theodore Barry and Associates, Los Angeles, for outstanding research assistance and to the Ford Foundation for financial support for the project. The analyses of variance and other computations were carried out on an IBM 709 through the courtesy of the Western Data Processing Center of the Graduate School of Business Administration, University of California, Los Angeles.

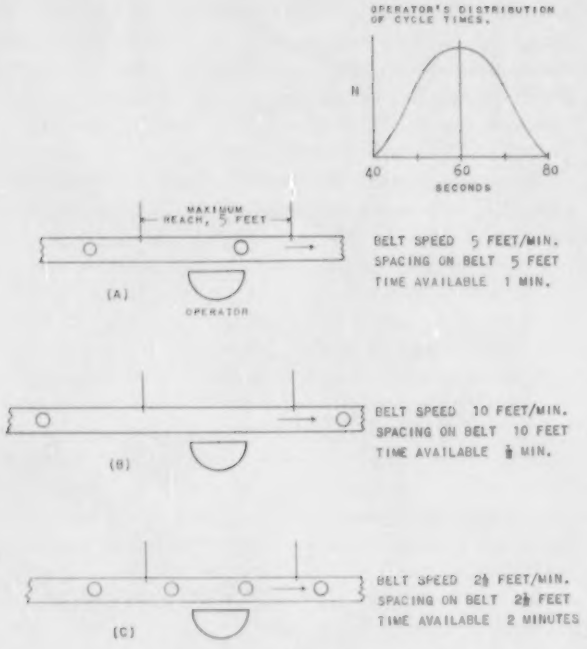

FIGURE 1. Effect of Belt Speed and Spacing on Time Available of Units to Operator.

for parts up or down the line, a total distance of five feet. The line is balanced for a rate of 60 units per hour and the particular operation shown has an average output of 60 units per hour with a time distribution shown in the upper right hand corner of Figure 1. With a requirement of 60 units per hour, or 1 per minute, the belt speed depends on how far apart the units are spaced on the conveyor. Thus, if parts are spaced five feet apart, as in (A) of Figure 1, the belt speed is, (1 unit per minute) × (5 feet between units) = 5 feet per minute, or 10 feet per minute with a 10-feet spacing, etc. The time that each part is available to the operator is determined directly by the selection of the combination of spacing and belt speed. The units would be available one minute at a belt speed of five feet per minute, ½ minute at 10 feet per minute, 2 minutes at a speed of 2½ feet per minute, etc. The fact that the operator can reach up and down the line for the units has the equivalent effect of finite queues in Hunt's analysis shown in Table 1.

We are now in a position to give a general answer to the question raised previously about the alleged foreman's speed-up of the line. If he sped up the line, he was reducing the effective queue between operations. Since the spacing between units was undoubtedly not changed, the net effect on output is not entirely clear. Unprocessed units could have counterbalanced the increase in the rate of flow of the units. Completing this processing off-line is commonly more costly. If the line was already below maximum possible utilization (following Hunt's analysis), slowing the line could have actually increased net output by increasing the effective queues between operations, a paradoxical result indeed.

The studies and analyses previously cited indicate that productivity is definitely linked to time available in a paced situation. The following experimental study attempts to gain some insight into the effect of rate of feed and time available on specific manual elements within a task as well as on the total work time of the cycle.

METHOD

Figure 2 shows the workplace layout that was used to test the hypothesis that feed rate and time available are variables affecting element times measured and average work cycle time. The task required the subject to assemble two parts in a fixture. Part A was a pin (1½ inches long, ¼ inch in diameter, chamfered on one end). Part B was a bushing (¾ inch in diameter, ½ inch thick, and with a concentric hole 0.26 inch in diameter).

Part A was fed from a dual feeder at predetermined rates. The subject grasped the pins from the wells, pressed the manual advance buttons, and then moved the pins to the fixture, positioning them in holes 1 and 4, chamfered end down. (The pins were fed to the wells with the chamfered ends always pointing outward. The time that the pins remained available to the subject depended on the opening of solenoid operated trap doors in these wells, and could be varied by the experimenter at three different levels). Part B, the bushings, were then procured from supply bins and assembled into holes 2 and 3. The subject then pressed the disposal buttons, energizing a solenoid which caused the parts in the fixture to drop into a chute. Finally, the subject placed his hands on the idle bar located in front of the Part A wells to wait for the next pins to appear. The cycle was then repeated. The list of manual elements for the right hand follows:

1. Reach to Part A.
2. Grasp Part A.
3. Move to manual advance button, depress button.
4. Move part A to hole 3 in fixture.
5. Position Part A in hole and release.
6. Reach to Part B.

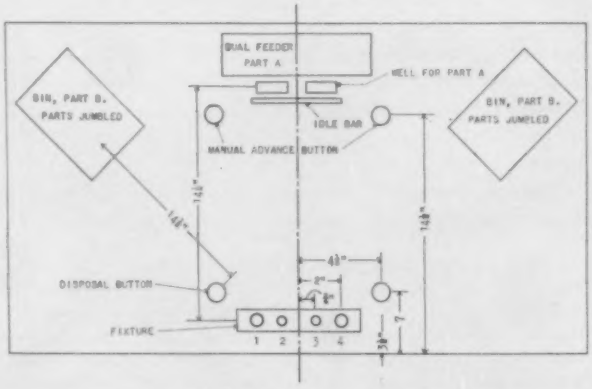

FIGURE 2. Workplace Layout.

7. Grasp Part B.
8. Move Part B to hole 4 in fixture.
9. Position Part B in hole and release.
10. Reach to disposal button.
11. Depress button.
12. Reach to idle bar.
13. Remain in contact with idle bar until the next pin is available.

The table height was set at 28 inches and an adjustable chair was used to vary the height of the subject in relation to the table so that his elbow was about 3 inches above the table top with erect sitting posture.

Five different rates of feed were combined with three different times available in a factorial experiment, yielding 15 combinations of the paced experimental variables. To this was added an unpaced condition so that each subject was presented with 16 experimental conditions. The cycle for the unpaced condition remained the same, pins being fed to the operator from the feeder when the manual advance buttons were pressed. The five rates of feed corresponded to paced cycle times of 5, 6, 7.5, 10 and 15 seconds. The fastest cycle time required a very high performance by the subjects. The three times available were 2, 3, and 4 seconds. The manual cycle remained identical for all combinations of the experimental variables.

For all subjects, the time measurements made of the right hand were:

Channel 1, Grasp plus move to fixture of Part B. Elements 7 and 8.

Channel 2, Positioning of Part B in fixture. Element 9.

Channel 3, Press disposal button and reach to idle bar. Elements 11 and 12.

Channel 4, Time in contact with idle bar. Element 13. Average work cycle time could then be determined by subtracting the idle time from the total cycle time.

INSTRUMENTATION

To instrument the work place the Electronic Time Recorder (ETR) was used. All wiring was under the table with no direct connections to the subject. The ETR operates on an electronic switching principle so that when the subject touches certain contact points on the work place in the performance of the task, electronic counters are turned on or off to accumulate the desired time values accurately. For a more complete description of the operation and use of the ETR see (1).

SUBJECTS AND EXPERIMENTAL ROUTINE

Twenty male university students with preferred right-handedness served as subjects. All subjects were trained and allowed to practice for about 150 cycles at various levels of pacing before any data were taken. In addition, after the initial training and practice period, the subject was allowed to practice 30-40 cycles on each combination of the experimental variables before any measurement took place, however, the subject was not told exactly when measurement was to begin. In every instance, 10 cycles were measured accumulatively for each of the four measurements made. The 16 combinations of the experimental variables were presented in random order to the subjects. When the unpaced combination was presented to the subject, he was instructed to perform at a pace which he felt he could maintain over a normal work day. The total time per subject including training and practice averaged two hours and forty minutes. For each of the four measurements made there resulted 320 items of data, since each of the 20 subjects performed under each of the 16 combinations of experimental conditions.

TABLE 2

Analysis of Variance, Channel 1; Log of Time for 10 Cycles of "Grasp Plus Move to Fixture of Part B"

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F
Subjects	19	1.20632	0.06349	23.77*
Rate of Feed	4	0.12626	0.03157	11.82*
Time Available	2	0.00078	0.00039	0.146***
Residual	274	0.73185	0.00267	
Total	299	2.06519		

* $p < 0.01$; *** not significant. Other interactions were not significant and were combined in residual.

RESULTS AND DISCUSSION

In programming the IBM 709 to perform the analysis of variance shown in Tables 2, 3, 4, and 5 the data were converted to logarithms, a common transformation used to normalize performance time distributions.

In all four of the measurements made, subjects and rate of feed were found to be significant at beyond the 1 percent level, with the exception of rate of feed for the Channel 2 measurements (position Part B in fixture) which was significant above the 5 percent level. The subject effect is common in these types of experiments, and is not of central interest. The effect of rate of feed on the measurements made is highly significant and Figure 3 is a graph of the average values for the four measurements versus the imposed cycle times. In general, the time measurements made are reduced as the imposed cycle time becomes smaller. An exception is the Channel 2

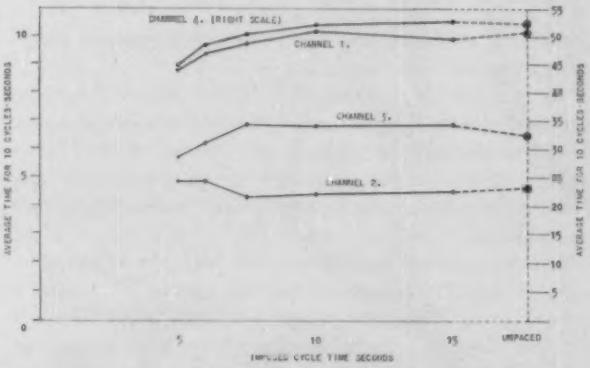

FIGURE 3. Average Time versus Imposed Cycle Time.

TABLE 3

Analysis of Variance, Channel 2; Log of Time for 10 Cycles of "Position Part B in Fixture"

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F
Subjects	19	1.72097	0.09058	10.48*
Rate of Feed	4	0.11199	0.02800	3.24**
Time Available	2	0.00345	0.00172	0.199***
Residual	274	2.36737	0.00864	
Total	299	4.20378		

* $p<0.01$; ** $p<0.05$; *** not significant. Other interactions were not significant and were combined in residual.

TABLE 4

Analysis of Variance, Channel 3; Log of Time for 10 Cycles of "Press Disposal Button and Reach to Idle Bar"

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F
Subjects	19	1.55272	0.08172	14.751*
Rate of Feed	4	0.23650	0.05913	10.673*
Time Available	2	0.00989	0.00494	0.892***
Interaction: Subjects × Rate of Feed	76	0.78453	0.01032	1.863**
Residual	198	1.09680	0.00554	
Total	299	3.68045		

* $p<0.01$; ** $p<0.05$; *** not significant. Other interactions were not significant and were combined in residual.

TABLE 5

Analysis of Variance, cycle time—Channel 4; Log of Time for 10 Cycles of "Work Time Cycle"

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square	F
Subjects	19	0.20856	0.01098	15.123*
Rate of Feed	4	0.18358	0.04589	63.209*
Time Available	2	0.00064	0.00032	0.441***
Interaction: Rate of Feed × Time Available	8	0.01390	0.00174	2.385**
Residual	266	0.19320	0.00073	
Total	299	0.59987		

* $p<0.01$; ** $p<0.05$; *** not significant. Other interactions were not significant and were combined in residual.

measurement which has the reverse relationship, but a rather small effect.

Time available was not significant in any of the measurements made. While, overall productivity is affected by the time available criterion as per Conrad (2) and Hunt (3), it is because parts may go by unprocessed and not because internal elements or average work cycle times are affected.

For the average work cycle time only, the interaction, rate of feed × time available, was significant at the 5 percent level. Thus, while time available, taken by itself was not effective, in combination with rate of feed, short times available contribute to reduce average work cycle times as imposed cycle times are also reduced.

The unpaced condition is plotted as a point in Figure 3 for each of the four measurements made, connected by a dotted line to the associated paced measurements. The times observed for the four measurements made for the unpaced condition are comparable to the paced conditions where the subject was not under heavy pace pressure.

CONCLUSIONS

Results of the present experiments indicate that actual performance times are not a function of time available, but a function of feed rate only.

The practical conclusion of the Conrad, Hunt, and the present experimental studies taken together indicate the following design criteria:

1. Where possible parts should not be fixed rigidly to conveyors. The system should be designed so that banks can build up between operations, allowing maximum flexibility to manual operations.

2. Where rigid pacing seems necessary:

a. Maximum flexibility should be provided by selecting part spacing-belt speed combinations which minimize belt speeds. This amounts to spacing parts as is consistent with good work methods.

b. Additional flexibility can be obtained by extending the effective time available through the layout design, that is, allowing space for operators to walk up and down the line to complete work or to intercept parts early.

c. The designer can expect some compensation by the operator to increased belt speeds or feed rates. This response is very small, however, being only about 10 percent in cycle time compared to unpaced cycle times. This increase in worker pace, however, may be counterbalanced, partially or completely, by an increase in the number of parts that go by unprocessed.

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Rate of Return: A Comparison Between Accurate and Approximate Methods for the Nonuniform Income Case

by HOWARD S. KRASNOW

Staff Assistant for Operations Research, Hamilton Standard Division of United Aircraft Corporation

THE PRINCIPLE of recognizing compound interest in establishing the expected profitability of an investment has long been recognized (1). The most widely accepted measure of profitability is the "internal rate of return on investment" (or simply "rate of return"), defined as that interest rate which equates the investment stream to the stream of cash receipts on the investment.[1] It is stated explicitly by Equation 6 for the case in which the investment stream is concentrated at the start of the investment project and interest is compounded annually. For reasons familiar to most Industrial Engineers, numerous other "definitions" of rate of return exist and are frequently employed. Most of these can be viewed as approximations to the internal rate of return.

Given that net income after tax constitutes a uniform annual series, standard compound interest factor tables can readily be employed to determine the rate of return (1), (2). Furthermore, for those who cannot avoid the use of an approximation, the error introduced by the approximation can often be established (4). Unfortunately, in practice net income is not likely to be so cooperative. Several factors usually lead one to expect nonuniform income from an investment. To begin with, even if the gross return is expected to be uniform, a nonuniform depreciation (that is other than straight-line depreciation) will lead to nonuniform income taxes and hence nonuniform net income. Expected changes in work load, increasing maintenance costs, and uncertainty about returns in the distant future are typical of factors which may generate a nonuniform estimate of gross return.

The following discussion, which is concerned with some of the problems created by nonuniform net income streams, is in two parts. The first is an analytical treatment of the zero salvage value case in which gross return, before depreciation and income tax, is a uniform series. The impact of depreciation method on both the internal rate of return and on a particular approximate rate of return will be evaluated, demonstrating that the impact can be far more severe in the latter case. The second part is an illustration of the ease with which all such difficulties can be eliminated when electronic computational facilities are available.

[1] An alternative measure, with perhaps equal claim to validity, is the Profitability Index, defined as the ratio of the present value of cash returns on investment to the present value of all capital to be invested, with discounting based upon the cost of capital. For a discussion of the relative merits of these two methods, see (3).

IMPACT OF DEPRECIATION METHOD ON INTERNAL RATE OF RETURN

Under most circumstances, one is concerned with rate of return on investment after tax. Although it is possible to think in terms of rate of return before depreciation and tax, in which case the rate will be independent of income tax rate and depreciation method, this discussion will deal only with after-tax return.

The following symbols and definitions will be used throughout:

P = Capital Investment	= Cash committed to a long term project at time zero (dollars).
D = Depreciation	= A percentage d of the capital investment (dollars annually).
n = Project Life	= Expected economic life of the investment (years).
R = Gross Return	= Gross Sales less all applicable expenses except depreciation (dollars annually).
Net Income Before Tax	= Gross Return less depreciation dollars annually).
T = Income Tax	= A fixed percentage t of Net Income Before Tax (dollars annually).
Net Income	= Net Income Before Tax, less Income Tax (dollars annually).
C = Cash Flow	= Gross Return less Income Tax.
	= Net Income plus Depreciation (dollars annually).
i = Internal Rate of Return	= That interest rate which equates the *present value of*

projected cash flow with the *capital investment*, hence rate of return after tax (decimal percent).

r = Approximate Rate of Return = (Defined in next section).

F = Capital Recovery Factor $= \dfrac{1}{\sum_{k=1}^{n} \dfrac{1}{(1+i)^k}} = \dfrac{i(1+i)^n}{(1+i)^n - 1}$

From these definitions we have:

$$C = R - T = (1 - t)R + tD \qquad \text{Eq. 1.}$$

Replacing t by the present maximum Federal Corporate Tax Rate of 52 percent

$$C = .48R + .52D \qquad \text{Eq. 1a.}$$

From the viewpoint of an over-all income statement, Eq. 1. is valid only when $R \geq D$, that is when net income before tax is positive. However, when viewing an individual investment project which contributes only marginally to the total income, the relation will hold for negative before-tax income (on the project), provided the total net income of the firm before tax remains positive. This is assumed to be the case.

The total depreciation over the life of a project is equal to the investment, and hence independent of depreciation method. However, Eq. 1. shows that depreciation method, because depreciation is a tax deductible expense, affects the cash flow at any stage of a project. Accelerated depreciation has the effect of shifting the over-all cash flow toward the earlier years, hence imparting a higher present value to the cash flow with a resultant increase in rate of return. The question to be answered is: "How significant is this increase likely to be, and how can it be calculated?"

RATE OF RETURN UNDER STRAIGHT-LINE DEPRECIATION

Cash Flow C forms a uniform annual series whenever gross return does, hence tables of compound interest factors may readily be used in this case. Specifically,

$$P = \frac{C}{F} \qquad \text{Eq. 2.}$$

A derivation of this relation is provided in (1).

Straight-line depreciation is defined by $D = P/n$. Substituting in Eq. 2. for C,

$$F = .48\frac{R}{P} + \frac{.52}{n} \qquad \text{Eq. 3.}$$

The standard tables may readily be used, performing the table look-up based on Eq. 2. The implicit assumption has now been made that the investment is depreciated over the full life of the project. In practice, this assumption is often violated.

One basis for comparison of contrasting methods is to consider limiting values of rate of return as the project life becomes very large. In the limit, F approaches i, hence by Eq. 3., i approaches $.48(R/P)$, as the last term goes to zero. Under no income tax ($t=0$), i approaches R/P as expected.

RATE OF RETURN UNDER SUM-OF-THE-YEARS-DIGITS DEPRECIATION

Let us now compare the preceding results with the exact determination of rate of return under a method of accelerated depreciation. Since the solution depends upon the particular method used, the sum-of-the-years-digits method has been chosen for purposes of illustration.[2] In this approach, the digits corresponding to the number of years of depreciation 1 to n are added together. The depreciation rate d in the first year equals n divided by this sum; in the second year n is replaced by $n-1$; in the third year by $n-2$; and so on to the nth year for which $d=1$ divided by the sum of the digits. The actual depreciation charged in the jth year is therefore:

$$D_j = d_j P = \left[\frac{n - j + 1}{\sum_{k=1}^{n} k}\right] P; \qquad 1 \leq j \leq n \qquad \text{Eq. 4.}$$

Substituting in Eq. 1a., to evaluate cash flow in the year j, we obtain directly

$$C_j = .48R + .52\left[\frac{(n+1)P}{\sum_{k=1}^{n} k} - \frac{Pj}{\sum_{k=1}^{n} k}\right] \qquad \text{Eq. 5.}$$

which holds for all j provided we again assume that the project is depreciated over its full life.

Depreciation D, and therefore cash flow C no longer constitute uniform series, hence Eq. 2. (and therefore tables of compound interest factors) cannot readily provide an exact determination of rate of return i. Turning to the definition of rate of return, and noting that the present worth of an amount C_j at the end of j years is given by

$$\frac{C_j}{(1+i)^j},$$

this rate of return is determined by[3]

$$P = \frac{C_1}{(1+i)} + \frac{C_2}{(1+i)^2} + \cdots + \frac{C_j}{(1+i)^j}$$

[2] An alternate approach is demonstrated in (1), Chapter 15.

[3] Eq. 6. is not strictly exact because cash flow is not likely to form the discrete annual series pictured here. In addition, certain cash flows can create a situation in which a unique solution to this equation does not exist. Under most practical circumstances these defects are not significant, so that Eq. 6. will be treated as the exact determination of rate of return for comparison purposes.

$$+ \cdots + \frac{C_n}{(1+i)^n} \qquad \text{Eq. 6.}$$

Substituting for C_j from Eq. 5., and grouping terms, we get

$$P = .48R \sum_{j=1}^{n} \frac{1}{(1+i)^j} + \frac{.52(n+1)P}{\sum_{k=1}^{n} k} \sum_{j=1}^{n} \frac{1}{(1+i)^j} - \frac{.52P}{\sum_{k=1}^{n} k} \sum_{j=1}^{n} \frac{j}{(1+i)^j} \qquad \text{Eq. 7.}$$

However,

$$\sum_{j=1}^{n} \frac{1}{(1+i)^j}$$

is precisely the reciprocal of the capital recovery factor $(1/F)$. Eq. 7. can therefore be rearranged into the following form

$$\frac{R}{P} = \frac{1}{.48}\left(F - \frac{.52}{n}\right) + \frac{1}{.48}\left(\frac{.52F}{\sum_{k=1}^{n} k} \sum_{j=1}^{n} \frac{j}{(1+i)^j} - \frac{.52}{n}\right) \qquad \text{Eq. 7a.}$$

COMPARISON OF THE TWO SOLUTIONS

The equation for determining rate of return in the case of straight-line depreciation can be rewritten in the form

$$\frac{R}{P} = \frac{1}{.48}\left(F - \frac{.52}{n}\right) \qquad \text{Eq. 3a.}$$

The right hand side of this equation is identical to the first term on the right side of Eq. 7a. Hence, the second term represents the difference between the two calculations under the two methods of depreciation. By inspection, it is seen that this difference term is zero for $n=1$. The value of the term also approaches zero in the limit as $n \to \infty$; hence, in the limit the two solutions are identical and $i=.48(R/P)$ regardless of depreciation method. If this difference term is small for intermediate, practical values of n, then a calculation based on the assumption of straight-line depreciation (using compound interest tables and Eq. 3.) will provide a good approximation to the true rate of return when the depreciation method is actually sum-of-the-years-digits.

This, in fact, turns out to be the case, and the accuracy of the approximation is illustrated in Figure 1 for selected values of the ratio R/P.

This figure presents the absolute difference expressed in percentage points, of the rate of return as calculated by Eq. 7a. (for sum-of-the-digits depreciation) compared with the rate as calculated by Eq. 3. (assuming straight-line depreciation). The difference is always positive, that

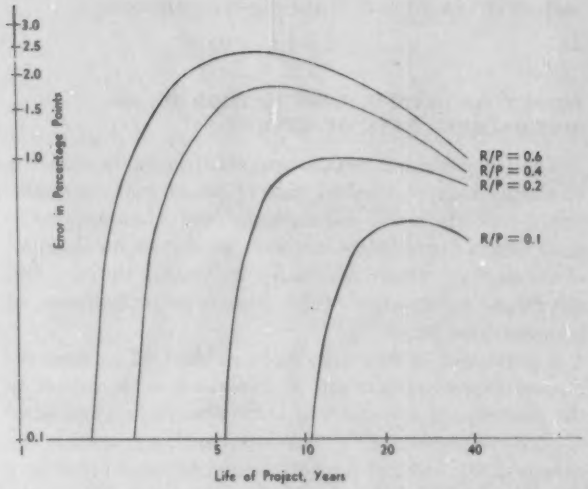

FIGURE 1. Absolute Error of Internal Rate of Return when Computation is Based on Straight-Line Depreciation, Given that Depreciation is Actually by Sum-of-Digits. Correct Rate of Return (Eq. 7a.) = Calculated Rate of Return (Eq. 3.) plus error.

is the assumption of straight-line depreciation always leads to an understatement of the true rate of return, as already anticipated. Figure 1 can be used directly to determine the correct rate of return using the straight-line method, although this refinement may not be significant due to the small magnitude of the error. It is also worth noting that the percentage error decreases for increasing values of R/P (and hence rate of return).

The expectation of either a negative or positive salvage value at the end of the project life could significantly effect the error shown in Figure 1. The analytical formulation of this case is more complex, and the results would be dependent upon the ratio of salvage value to initial investment, as well as upon project life.

NUMERICAL EXAMPLE

The following example is presented as a means of summarizing this discussion:

Let P = Capital Investment = \$1000
R = Gross Return = \$400 per year
t = Tax Rate = 52%
n = Project Life = Depreciation Life = 11 years
Method of Depreciation = Sum-of-the-years-digits.

a. Assume the use of straight-line depreciation

$$F = .48\left(\frac{400}{1000}\right) + \frac{.52}{11}$$

$$F = .192 + .047 = .239 \qquad \text{Eq. 3.}$$

Referring to compound interest factor tables, and using linear interpolation, we find $i \cong 21.0\%$ if straight-line depreciation had been used.

b. Figure 1 shows that the absolute error in this approximation for $R/P=.4$ and $n=11$ is 1.8%, hence the

correct return for sum-of-the-digits depreciation is

$$i = 21.0 + 1.8 = 22.8\%$$

IMPACT OF DEPRECIATION METHOD ON AN APPROXIMATE RATE OF RETURN

The foregoing conclusion may seem to imply that any method for approximating rate of return using straight-line depreciation will work equally well when applied to nonuniform depreciation methods (or at least for the sum-of-the-digits method). This is not necessarily the case, and significant errors may result from such extensions, as demonstrated below.

A particular, commonly employed method for approximating rate of return will be evaluated with respect to the true rate of return using both straight-line and sum-of-digits depreciation. We are interested primarily in the change in the error of the approximation introduced by a change in depreciation method; and secondarily in the absolute values of the errors as a measure of the overall adequacy of this particular method of approximation. It is assumed throughout that gross return R forms a uniform series over the life of the project, and that the investment is depreciated over this full life.

ERROR OF APPROXIMATION UNDER STRAIGHT-LINE DEPRECIATION

Consider the calculation

$$r = \frac{\text{Average "cash profit" over the life of the project}}{\text{Average outstanding (that is undepreciated) investment}}.$$

Where average "cash profit" is defined as $1/n \times$ cumulative cash flow in excess of original investment; and average outstanding investment equals

$$\frac{1}{n}\sum_{k=1}^{n}$$

(outstanding investment at the end of year k). Obviously, r is an attempt to determine an "average" rate of return on investment over the life of the project. The outstanding investment at the end of year k can be expressed as

$$\left(P - \sum_{j=1}^{k} D_j\right)$$

hence

average outstanding investment

$$= \frac{1}{n}\sum_{k=1}^{n}\left(P - \sum_{j=1}^{k} D_j\right) \qquad \text{Eq. 8.}$$

Introducing straight-line depreciation for which

$$\sum_{j=1}^{k} D_j = kD = \frac{kP}{n},$$

Eq. 8. becomes

average outstanding investment

$$= \frac{1}{n}\left(nP - \frac{P}{n}\sum_{k=1}^{n} k\right) = \frac{P}{n}\left(n - \frac{\sum_{k=1}^{n} k}{n}\right) \qquad \text{Eq. 8a.}$$

Since cash flow is a uniform series, the definition of average "cash profit"

$$\text{average "cash profit"} = \frac{1}{n}(nC - P) \qquad \text{Eq. 9.}$$

and the definition of approximate rate of return is:

$$r = \frac{nC - P}{\frac{P\left(n - \sum_{k=1}^{n} k\right)}{n}} \qquad \text{Eq. 10.}$$

Substituting for C by Eq. 1a., and using the identity

$$\sum_{k=1}^{n} k = \frac{n(n+1)}{2},$$ yields

$$\frac{R}{P} = \frac{1}{.48}\left[\frac{r}{n}\left(\frac{n-1}{2}\right) + \frac{1}{n} - \frac{.52}{n}\right] \qquad \text{Eq. 10a.}$$

Equating this with Eq. 3a. which gives the true rate of return, for any given value of R/P,

$$\frac{r}{n}\left(\frac{n-1}{2}\right) + \frac{1}{n} - \frac{.52}{n} = F - \frac{.52}{n} \qquad \text{Eq. 11.}$$

or

$$r = \frac{2}{n-1}(nF - 1) \qquad \text{Eq. 11a.}$$

where F is, of course, the capital recovery factor based on R/P and Eq. 3.[4]

Eq. 11a. shows that in the limit, as $n \to \infty$, $r \to 2i$, which is a rather poor approximation. Figure 2 is a graphical presentation of this equation expressed in terms of the percentage deviation of r from i, for selected values of i. It is seen that the approximation is not an especially good one in any range, and becomes extremely poor for very short project life, as well as for very long project life. "Estimating curves" which permit ready conversion of the approximate value r to the true rate of return i can be developed. However, these offer no advantage in ease of use over the direct determination of i and have therefore been omitted.

ERROR OF APPROXIMATION UNDER SUM-OF-THE-YEARS-DIGITS DEPRECIATION

We shall now consider this same approximation method when sum-of-the-digits depreciation is employed,

[4] If average outstanding investment were defined as one half of the initial investment, Eq. 11a. would have been

$$r = \frac{2}{n}(nF - 1) = 2\left(F - \frac{1}{n}\right).$$

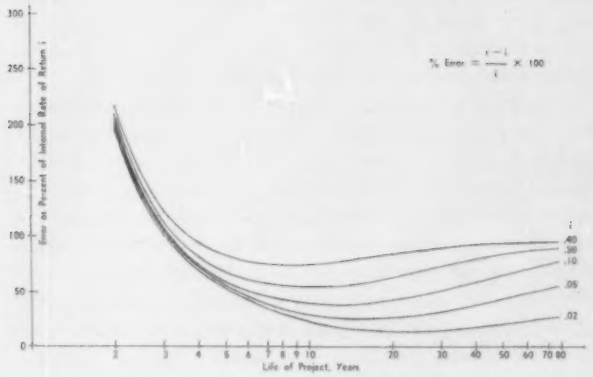

FIGURE 2. Percent Error of Approximate Rate of Return r (Eq. 10.) for Selected Values of the Internal Rate of Return i (Eq. 3.) Straight-Line Depreciation.

to determine whether or not the error is comparable. In contrast to the straight-line case, the determination of the approximate return r is now a somewhat lengthy calculation. The average outstanding investment, multiplied by n, is the sum of the outstanding investments at the end of each year, hence

n(average outstanding investment)

$$= nP - \{nD_1 + (n-1)D_2 + \cdots + [n-(n-1)]D_n\} \quad \text{Eq. 12.}$$

$$= nP - \sum_{j=1}^{n} (n-j+1)D_j \quad \text{Eq. 12a.}$$

$$= nP - (n+1)\sum_{j=1}^{n} D_j + \sum_{j=1}^{n} jD_j \quad \text{Eq. 12b.}$$

Substituting for D_j from Eq. 4., and using the identity

$$\frac{\sum_{j=1}^{n} j^2}{\sum_{k=1}^{n} k} = \frac{2n+1}{3},$$

this reduces to

$$n\text{(average outstanding investment)} = \frac{(n-1)P}{3} \quad \text{Eq. 12c.}$$

The average "cash profit" as defined in the preceding section, is

$$\text{average "cash profit"} = \frac{1}{n}\left(\sum_{j=1}^{n} C_j - P\right) \quad \text{Eq. 13.}$$

Hence the approximate rate of return is given by

$$r = \frac{\sum_{j=1}^{n} C_j - P}{\frac{P(n-1)}{3}} \quad \text{Eq. 14.}$$

Substituting for C_j from Eq. 5., and rearranging,

$$\frac{R}{P} = \frac{1}{.48}\left(\frac{n-1}{3n}r + \frac{.48}{n}\right) \quad \text{Eq. 14a.}$$

Equating this with Eq. 7a. which gives the true rate of return, for any given value of R/P,

$$\frac{n-1}{3n}r + \frac{.48}{n} = F - \frac{2(.52)}{n} + \frac{.52F}{\sum_{k=1}^{n} k}\sum_{j=1}^{n} \frac{j}{(1+i)^j} \quad \text{Eq. 15.}$$

or

$$r = \frac{3}{n-1}\left(nF - 1.52 + \frac{2(.52F)}{n+1}\sum_{j=1}^{n} \frac{j}{(1+i)^j}\right) \quad \text{Eq. 15a.}$$

COMPARISON OF THE TWO APPROXIMATIONS

The approximation, as given by Eq. 15a., is extremely poor, with the limiting value of r equal to $3i$. While the situation is not this bad for practical values of n, Figure 3 shows an appreciable error over the entire range. A comparison of Figure 3 with Figure 2 reveals that the error of the approximation is roughly doubled when it is applied to the sum-of-the-digits case. It was demonstrated in the preceding section that the internal rate of return changes only slightly when the method of depreciation is changed from straight-line to sum-of-the-digits. It follows, therefore, that the large increase in error of the approximation, under a similar change in depreciation method, is due to the process by which the approximation incorporates depreciation. It would obviously be preferable to ignore actual depreciation method and arbitrarily assume

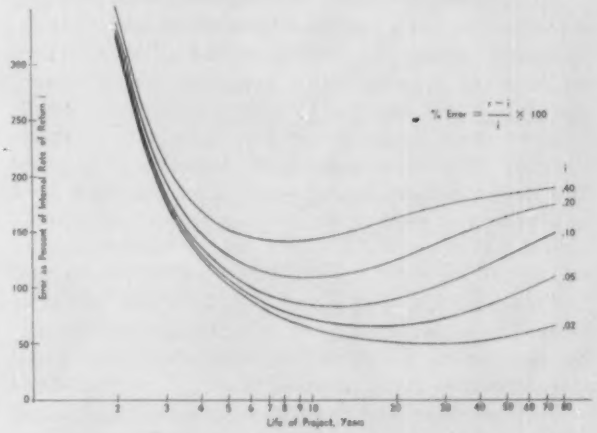

FIGURE 3. Percent Error of Approximate Rate of Return r (Eq. 14.) for Selected Values of the Internal Rate of Return i (Eq. 7a.) Sum-of-the-Years-Digits Depreciation.

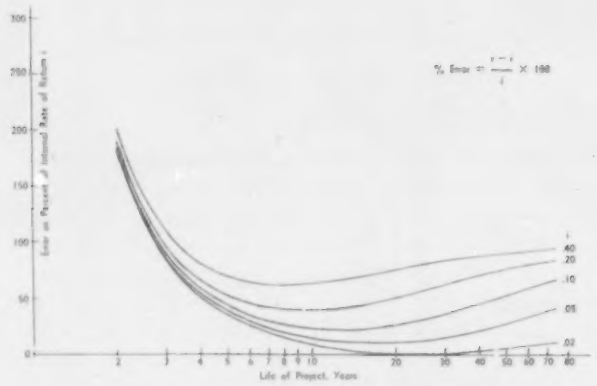

FIGURE 4. Percent Error of Approximate Rate of Return r, Computed with Straight-Line Depreciation (Eq. 10.) for Selected Values of the Internal Rate of Return i (Eq. 7a.) Sum-of-the-Years-Digits Depreciation.

straight-line depreciation by applying Eq. 10. in all cases. Since the approximation errs on the side of overstatement, and the assumption of straight-line depreciation (where accelerated depreciation is being used) tends to understate the rate of return, the resulting error is actually somewhat less than when Eq. 10. is applied as intended for straight-line depreciation. This compound error is shown in Figure 4. Even in this case, the approximation is not consistently good. The procedure suggested in the preceding section is certainly preferable, both from the viewpoint of ease and accuracy.

The sensitivity of this approximation to the method of depreciation actually employed is an indication of its sensitivity to differing cash flow structures. If the approximation were to be applied for the purpose of comparing alternative proposals having nonuniform, and different, gross returns (even under the same method of depreciation) appreciable relative error would be possible.

THE GENERAL CASE AND A COMPUTER SOLUTION

The foregoing discussion was concerned with the effect of income tax and a particular nonuniform method of depreciation on the determination of rate of return. There are, however, numerous other conditions arising in practice which might distort or invalidate calculations; conditions which are probably far more difficult to treat analytically. A prime example is the departure of gross return from a uniform annual series, which can occur for a wide variety of reasons. Even if one is satisfied with assuming that gross return is uniform, the depreciation life can depart appreciably from the expected project life. Yet the assumption of equal lives for these factors is implicit in most methods of calculation. Furthermore, the assumption of zero salvage value may prove to be unreasonable in many practical cases.

The electronic computer offers an extremely simple and economical way out of this entire problem. The increasing availability of computers (and in this case they need not be large scale) makes this a practical approach for most firms today. The following is a brief description of what has been done at the Hamilton Standard Division of United Aircraft Corporation. All proposals for Capital Investment are now prepared in this manner.

Operating departments prepare a worksheet to support any proposal for capital investment. This worksheet yields a year by year estimate of the "gross profit" (Gross Return R) expected from the investment over its entire life. Expenses which are a function of outstanding investment or gross return, such as depreciation, property taxes, income taxes, or insurance are calculated by the computer. Supplementary information describing the project and indicating the method and period of depreciation completes the computer input. Rate of Return, based on Eq. 6., is calculated by a simple, systematic, trial and error procedure. The computer output (Figure 5) provides a document for use directly by management in the evaluation phase. A typical case (such as the hypothetical example shown) requires only a few seconds of time on the IBM 705 computer. The effort of calculating rate of return, by whatever method, is of course eliminated. Far more important, however, is the ability to determine rate of return consistently and reliably regardless of the special conditions of the project. An important by-product is the ability to systematically explore regions of uncertainty in the estimates. For example, the sensitivity of rate of return to an estimate of equipment utilization can be studied to determine the range of utilization required for a desired level of profitability.

The results of one sensitivity analysis are presented in Figure 6. This is a case in which an automatic machine tool is being considered as a replacement for work currently being performed on older equipment. The estimate of gross return that will result from the use of the new machine depends directly on an underlying assumption

PROPOSAL FOR CAPITAL INVESTMENT

Proposal No.	42-10-61	Proposal Date	2-15-61
Title	Tape Controlled Milling Machine		
Estimated Cost			
	Present Worth of Capital Investment	108 725	Dollars
	Expense	0	Dollars
Project Life	12 Years	Depreciation Life 10	Years
Depreciation Method	Sum of the Years Digits		
Year of Initial Investment	1961		
Income Tax Rate	52 Percent	Property Tax Rate 1.38	Percent

SUMMARY OF INVESTMENT RESULTS

Rate of Return on Investment	26.5 Percent
Payout Time	3–4 Years

Anniversary Year	Gross Profit after Expense and before Depreciation	Cash Flow after Taxes	Net Income=Cash Flow Less Depreciation
1961	8499.	14359.	5408.–
1962	38772.	27862.	10070.
1963	64017.	38952.	23137.
1964	64236.	38028.	24191.
1965	64427.	37092.	25231.
1966	79590.	43343.	33459.
1967	79727.	42380.	34473.
1968	79836.	41405.	35474.
1969	79918.	40416.	36462.
1970	39972.	20214.	18238.
1971	40000.	19200.	19200.
1972	40000.	19200.	19200.

FIGURE 5

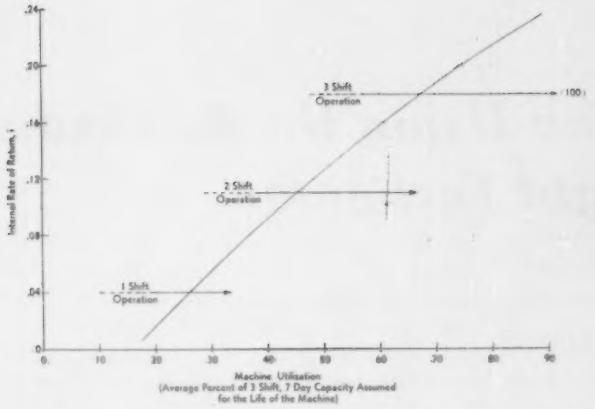
3 Shift Operation
2 Shift Operation
1 Shift Operation
Machine Utilization
(Average Percent of 3 Shift, 7 Day Capacity Assumed for the Life of the Machine)

FIGURE 6. Sensitivity of Internal Rate of Return to Assumed Level of Utilization for A Hypothetical Machine Replacement Problem.

concerning the level of utilization to be experienced. A series of estimates were prepared based upon several different assumptions, and the resulting rate of return is plotted as a function of percent utilization. In order to achieve a rate of return in the neighborhood of 10%, it is apparent that at least two-shift operation will be required. A rate of return beyond 18% can be achieved only by operating the equipment around the clock. The slope of the curve at any point provides a good measure of the relative error in computed rate of return corresponding to any given error in assumed utilization. Such knowledge can be extremely relevant in evaluating alternative investment opportunities.

SUMMARY

The calculation of rate of return on investment is often based on the assumption that net income constitutes a uniform series of receipts. Under this assumption, standard tables of compound interest factors provide a simple method for determining rate of return.

This assumption has been replaced by assuming that gross return, before depreciation and before tax, forms a uniform series; and that the investment is depreciated over the entire life of the project. Hence, the possibility of a nonuniform net income series (where depreciation is nonuniform) is introduced. It has been shown that:

1. If straight-line depreciation is used, standard tables may readily be used with the aid of a simple transformation on R/P.

2. If sum-of-the-years-digits depreciation is used, the assumption of straight-line depreciation and the application of the above method yields a very close approximation to the true return in the zero salvage value case. A method for further adjusting this approximation has also been demonstrated.

3. A particular, approximate method of calculation has been evaluated with respect to each of the two methods of depreciation. It is concluded that the error of the approximation may be influenced considerably by the method of depreciation employed, where depreciation enters into the approximating calculation.

The added complexities introduced by relaxing these assumptions provide a strong motivation for the use of a computer to provide a general solution. An illustration of this approach has been presented.

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Assembly Line Balancing Using the Ranked Positional Weight Technique

by **W. B. HELGESON**

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Systems Designer, Internal Automation Operation, Industrial Electronics Division, General Electric Company

IN 1954 the assembly line balancing problem was defined analytically in a paper given limited distribution in the General Electric Company (2). Prior to this, there were a few unpublished papers, one a masters thesis (1). M. E. Salveson authored the first published paper on assembly line balancing (5). This generated a great deal of interest in the profession. Several papers were published and one known computer routine was developed based on an approach outlined by James R. Jackson (3), (4), (6), (7). This presentation describes another computer routine developed for solving the assembly line balancing problem. This work was done in 1958 in the Home Laundry Department of the General Electric Company. The routine has been programmed for the Univac series of computers.

ASSEMBLY LINE CHARACTERISTICS

An assembly line is a moving conveyor that passes a series of work stations in a uniform time interval called the cycle time. At each work station, work is performed on a product either by adding parts or by completing assembly operations. The work performed at each station is usually made up of many bits of work at the "micro" level that can be described by motion-time analysis. Convenient groupings of these bits of work are called work units. Generally they are groupings that can not be subdivided on the assembly line without paying a penalty in extra motions.

The total work to be performed in an assembly work station is equal to the sum of the work units assigned to that station. The assembly line balancing problem is one of assigning all work units to a series of work stations so that each work station has no more work to perform than that allowed by the cycle time, and so that the unassigned time across all work stations is a minimum.

The problem is complicated by the relationships among work units imposed by product design and process technologies. This relationship is called the precedence relationship. It is a description of the ordering in which work units must be performed in the assembly operation. There are four precedence conditions:

1. *Must precede*—One work unit *must* be performed before another can be performed.
2. *Must not precede*—One work unit *must not* be performed until after another has been performed.
3. *No difference*—One work unit can be performed either before or after another.
4. *Not together*—One work unit must not be performed at the same work station as another because of technological limitations.[1]

Naturally, management wants the assembly operation to be performed in the most efficient manner possible. This means that manpower and equipment must not be wasted. Efforts must be made to keep the unassigned or idle time required to complete an assembly operation to a minimum.

Two formulations of the problem are possible:

1. Minimize the number of work stations for a given cycle time.
2. Minimize the cycle time for a given number of work stations.

The first formulation is the easier to solve, but rarely gives the best balances. It will be discussed first. The second formulation is the preferred formulation, and an alternative use of the technique to solve this formulation will be discussed. If two or more balances are equivalent by either of the above formulations, the preferred balance is the one with the most even distribution of work across the work stations.

APPROACHES TO BALANCING

Methods and time standards people normally attempt to solve the assembly line balancing problem manually. They use their experience to guide them in assigning work units to work stations. If they are not satisfied with the balance achieved, they rearrange the work unit assignments in the hope of achieving better results.

The ideal way to solve the assembly line balancing

[1] This technique as originally programmed handles this condition as if the "can't do's" are on a separate, short, linked line. A later program has taken the problem into account using "zoning" as is used in the IBM-Westinghouse routine (7).

problem is to determine all technologically feasible combinations for assigning work units for a given cycle time, and then select that set of combinations with the minimum unassigned time for each selected number of work stations. Generating all technologically feasible combinations is possible but not practical for most problems because of the matrix size, either manually or on the computer. It is necessary to resort to heuristic procedures that produce near optimal solutions in much less time. Such near optimal solutions get within a workable range of truly optimal solutions economically and can be audited by competent technicians for improvement. Our experience has indicated that *any* computer generated balance, even one generated by the "all possible combinations" approach, can be improved upon by a small percentage by competent technicians.

The approach outlined in this presentation is logically simple and requires only one iteration on a computer to achieve a solution for each selected cycle time. While the method does not guarantee optimal solutions to the assembly line balancing problem, experience has shown that solutions that are workably close to optimal are always achieved. In addition, for a given problem there are often a number of equivalent near-optimal solutions, that is, the same number of work stations for a given cycle time. When this is so, this method will almost always select one such solution.

DATA PREPARATION

The preferred method of describing the precedence relationships that exist among work units on an assembly line is the precedence graph because of its high degree of visualization of the relationships. The following precedence graph describes the illustrative problem to be used to demonstrate the logic of this technique.

This precedence graph illustrates that work unit *00* must be done before work units *02*, *05*, *06*, *07*, *08*, *09* and *10*. Similarly work unit *01* must be done before work units *02*, *03*, *04*, *05*, *06*, *07*, *08*, *09*, and *10*. Either work unit *00* or *01* may be done first. In like manner, work unit *02* can not be done until both work units *00* and *01* have been performed. Once work units *00* and *01* have been performed, either work unit *02* or *03* can be selected.

The ranked positional weight technique requires the use of a precedence matrix, an alternative presentation method to the precedence graph, to describe the precedence relationships. In the matrix a "+1" denotes a "must precede," a "−1" denotes a "must not precede," and a "0" denotes a "no difference" relationship. The precedence matrix for this problem follows:

work unit time	*work unit*	*00*	*01*	*02*	*03*	*04*	*05*	*06*	*07*	*08*	*09*	*10*
0.32	*00*	0	0	1	0	0	1	1	1	1	1	1
0.10	*01*	0	0	1	1	1	1	1	1	1	1	1
0.20	*02*	−1	−1	0	0	0	1	1	1	1	1	1
0.05	*03*	0	−1	0	0	1	0	0	0	1	1	1
0.10	*04*	0	−1	0	−1	0	0	0	0	1	1	1
0.23	*05*	−1	−1	−1	0	0	0	1	1	1	1	1
0.20	*06*	−1	−1	−1	0	0	−1	0	0	1	1	1
0.05	*07*	−1	−1	−1	0	0	−1	0	0	0	1	1
0.32	*08*	−1	−1	−1	−1	−1	−1	−1	0	0	1	1
0.10	*09*	−1	−1	−1	−1	−1	−1	−1	−1	−1	0	1
0.30	*10*	−1	−1	−1	−1	−1	−1	−1	−1	−1	−1	0
1.97												

The first row of the matrix shows that work unit *00* must precede work units *02*, *05*, *06*, *07*, *08*, *09*, and *10*. A completed matrix has a logical self checking feature. For every "+1" in the matrix (say row *00*, column *02*), there should be a "−1" in the complementary position (row *02*, column *00*). If this is not so, the recorded precedences are inconsistent.

POSITIONAL WEIGHT CALCULATIONS

The next step in the use of the technique is to calculate positional weights for each work unit. This is done by adding together the time values for the specific work unit and all work units that must follow it as defined in the precedence matrix. The matrix form of presentation makes the calculation very simple for the computer because every work unit that *must follow* the specified work unit is identified by a "+1" in the row-column intercept of the specified work unit and each following work unit. ("−1's" are ignored in making the positional weight calculation.) Thus, for work unit *00*, the positional weight is calculated as shown:

work unit	*00*	*01*	*02*	*03*	*04*	*05*	*06*	*07*	*08*	*09*	*10*
00	0	0	1	0	0	1	1	1	11	1	11
work unit time	.32		.20			.23	.20	.05	.32	.10	.30

positional weight = .32 + .20 + .23 + .20 + .05 + .32 + .10 + .30 = 1.73

In a similar fashion, the positional weights are calculated for all work units. Then the work units are sorted and listed in descending order of positional weights:

UNSORTED			*SORTED*		
work units	*positional weights*	*immediate precedence*	*work units*	*positional weights*	*immediate precedence*
00	1.73	—	*00*	1.73	—
01	1.65	—	*01*	1.65	—
02	1.40	*00* *01*	*02*	1.40	*00* *01*
03	0.87	*01*	*05*	1.20	*02*
04	0.82	*03*	*06*	0.92	*05*
05	1.20	*02*	*03*	0.87	*01*
06	0.92	*05*	*04*	0.82	*03*
07	0.45	*05*	*08*	0.72	*04* *06*
08	0.72	*04* *06*	*07*	0.45	*05*
09	0.40	*07* *08*	*09*	0.40	*07* *08*
10	0.30	*09*	*10*	0.30	*09*

The column called "immediate precedence" merely identifies those work units that are sequential immediately prior to the given work unit. This column simplifies the computer check that assures that no work element assignments are made that violate precedence relationships.

ASSIGNMENT RULES

The next step in the use of the technique is to assign work units to work stations. To do this, a cycle time is first selected. The assignment of work units is made giving first priority to those work units with the highest positional weight. The specific assignment rules are:

1. Select the work unit with the highest positional weight and assign it to the first work station. (It is assumed that one would not try to balance the line to a cycle time smaller than the time of the largest work element on the line, therefore the first assignable work unit can always be assigned to an empty work station.)
2. Calculate the unassigned time for the work station by calculating the cumulative time of all work units assigned to the station and subtract this sum from the cycle time.
3. Select the work unit with the next highest positional weight and attempt to assign it to the work station after making the following checks:
   a. Check the list of already assigned work units. If the "immediate precedent" work unit has been assigned, precedence will not be violated; proceed to step 3b. If the "immediate precedent" has not been assigned proceed to step 4.
   b. Compare the work unit time with the unassigned time. If the work unit time is less than the work station unassigned time, assign the work unit and recalculate unassigned time. If the work unit time is greater than the unassigned time, proceed to step 4).
4. Continue to select, check, and assign if possible until one of two conditions has been met:
   a. All work units have been assigned.
   b. No unassigned work unit remains that can satisfy both the precedence requirement and the "less than the unassigned time" requirement.
5. Assign the unassigned work unit with the highest positional weight to the second work station, and proceed through the preceding steps in the same manner.
6. Continue assigning work units to work stations until all work units have been assigned. At that time a solution to the assembly line balancing problem will have been found.

SAMPLE SOLUTION

Select a cycle time of 1.00

Assignments to Work Station 1

work unit	*positional weight*	*immediate precedence*	*work unit time*	*cumulative station time*	*unassigned station time*	*remarks*
00	1.73	—	0.32	0.32	0.68	assigned
01	1.65	—	0.10	0.42	0.58	assigned
02	1.40	*00 01*	0.20	0.62	0.38	assigned
05	1.20	*02*	0.23	0.85	0.15	assigned
~~*06*~~	~~0.92~~	~~*05*~~	~~0.20~~	~~1.05~~		rejected > *c*
03	0.87	*01*	0.05	0.90	0.10	assigned
04	0.82	*03*	0.10	1.00	0.00	assigned

It is obvious that another work station must be started.

Assignments to Work Station 2

work unit	*positional weight*	*immediate precedence*	*work unit time*	*cumulative station time*	*unassigned station time*	*remarks*
06	0.92	*05*	0.20	0.20	0.80	assigned
08	0.72	*04 06*	0.32	0.52	0.48	assigned
07	0.45	*05*	0.05	0.57	0.43	assigned
09	0.40	*07 08*	0.10	0.67	0.33	assigned
10	0.30	*09*	0.30	0.97	0.03	assigned

All work units have been assigned.

An attempt was made to assign *06* to station 1, but its work unit time exceeded the unassigned time. Rather than indicate all the internal checks, this has merely been shown by indicating a cumulative total greater than the cycle time. Since work unit *06* had the highest remaining positional weight, it was assigned first to station 2.

This solution required two work stations. The cumulative station time for station 1 was 1.00, a perfect assignment. The cumulative station time for station 2 was 0.97, leaving 0.03 unassigned. The unbalance by one formulation is $(0.03/1.97)\times100=1.52\%$. This formulation indicates that 1.52% additional work could be assigned to the line if it can be fit in. The alternative unbalance calculation is $0.03/2.00)\times100=1.5\%$. This indicates that the balance utilized 98.5% of the resources assigned. Generally, the first formulation is the preferred measure since it gives a good indication of the additional work that might be possible if it can be found and fit into the line.

In this case, no balance with less unassigned time is possible with a cycle time of 1.00 because no work element is smaller than 0.03. In most cases, however, it is well to try to determine if additional output can be obtained with the same number of work stations. To try this, a new problem is formulated with a cycle time of 0.99.

Assignments to Work Station 1

work unit	*positional weight*	*immediate precedence*	*work unit time*	*cumulative station time*	*unassigned station time*	*remarks*
00	1.73	—	0.32	0.32	0.67	assigned
01	1.65	—	0.10	0.42	0.57	assigned
02	1.40	*00 01*	0.20	0.62	0.37	assigned
05	1.20	*02*	0.23	0.85	0.14	assigned
~~*06*~~	~~0.92~~	~~*05*~~	~~0.20~~	~~1.05~~		rejected > *c*
03	0.87	*01*	0.05	0.90	0.09	assigned
~~*04*~~	~~0.82~~	~~*03*~~	~~0.10~~	~~1.00~~		rejected > *c*
~~*08*~~	~~0.72~~	~~*04 06*~~	~~0.32~~			rejected, *p*
07	0.45	*05*	0.05	0.95	0.04	assigned
~~*09*~~	~~0.40~~	~~*07 08*~~	~~0.10~~			rejected, *p*
~~*10*~~	~~0.30~~	~~*09*~~	~~0.30~~			rejected, *p*

All elements have been tried.

Assignments to Work Station 2

work unit	*positional weight*	*immediate precedence*	*work unit time*	*cumulative station time*	*unassigned station time*	*remarks*
06	0.92	*05*	0.20	0.20	0.79	assigned
04	0.82	*01*	0.10	0.30	0.69	assigned
08	0.72	*04 06*	0.32	0.62	0.37	assigned
09	0.40	*07 08*	0.40	0.72	0.27	assigned
~~*10*~~	~~0.30~~	~~*09*~~	~~0.30~~	~~1.02~~		rejected > *c*

Assignments to Work Station 3

work unit	*positional weight*	*immediate precedence*	*work unit time*	*cumulative station time*	*unassigned station time*	*remarks*
				0.00	0.99	
10	0.03	*09*	0.30	0.30	0.69	assigned

The solution to this problem has three work stations.

It was not possible to reduce the cycle time from 1.00 to 0.99 with this technique and still retain only two stations.

FINDING A MINIMUM CYCLE TIME FOR A GIVEN NUMBER OF WORK STATIONS

Early in our work it was recognized that it would be desirable to determine the minimum cycle time for a given number of work stations. This is equivalent to determining the maximum output for a given work force. Such a solution can be found on the computer with this technique by balancing the assembly line at various cycle times over a wide range of cycle times. It should be noted that the operationally limiting cycle time is not necessarily equal to the cycle time originally selected to be presented to the computer. The limiting cycle time is the cycle time of the station with the largest cumulative assigned time for a given problem solution. This may be, as in the foregoing example, less than the cycle time originally chosen, 0.95 being the limiting station time in station 1 versus 0.99 selected.

Thus, a simple method for finding the minimum cycle time for a given number of work stations can be found by selecting an arbitrary cycle time, balancing the line and determining the limiting station time. A second problem is then formulated with a cycle time one time increment smaller than the limiting station time. Successive iterations performed in this manner will lead to a minimum cycle time for a given number of work stations. This method has the advantage of bypassing many "in between" cycle times and thus reduces the number of iterations necessary for a solution. Following the example used above, let us now formulate a problem with a cycle time of 0.94. Without going into all the detailed steps as before, the following station assignments are obtained:

Work Station 1		*Work Station 2*		*Work Station 3*	
work unit	*cumulative station time*	*work unit*	*cumulative station time*	*work unit*	*cumulative station time*
00	0.32	*06*	0.20	*10*	0.30
01	0.42	*04*	0.30		
02	0.62	*08*	0.62		
05	0.85	*07*	0.67		
03	0.90 limiting	*09*	0.77		

Try cycle time = 0.89

Work Station 1		*Work Station 2*		*Work Station 3*	
00	0.32	*06*	0.20	*10*	0.30
01	0.42	*03*	0.25		
02	0.62	*04*	0.35		
05	0.85 limiting	*08*	0.67		
		07	0.72		
		09	0.82		

Try cycle time = 0.84

Work Station 1		*Work Station 2*		*Work Station 3*	
00	0.32	*05*	0.23	*09*	0.10
01	0.42	*06*	0.43	*10*	0.40
02	0.62	*08*	0.75		
03	0.67	*07*	0.80 limiting		
04	0.77				

Try cycle time = 0.79

Work Station 1		*Work Station 2*		*Work Station 3*	
00	0.32	*05*	0.23	*07*	0.05
01	0.42	*06*	0.43	*09*	0.15
02	0.62	*08*	0.75	*10*	0.45
03	0.67				
04	0.77 limiting				

Try cycle time = 0.76

Work Station 1		*Work Station 2*		*Work Station 3*	
00	0.32	*05*	0.23	*08*	0.32
01	0.42	*06*	0.43	*09*	0.42
02	0.62	*04*	0.53	*10*	0.72
03	0.67	*07*	0.58		limiting

Try cycle time = 0.71

Work Station 1		*Work Station 2*		*Work Station 3*		*Work Station 4*	
00	0.32	*05*	0.23	*08*	0.32	*10*	0.30
01	0.42	*06*	0.43	*09*	0.43		
02	0.62	*04*	0.53				
03	0.67 limiting	*07*	0.58				

Thus the minimum cycle time obtainable using this technique for three work stations is 0.72 or about 27% lower than the first balance for three work stations of 0.99. In a similar manner, the minimum cycle time for successively larger numbers of work stations can be found.

The results of the assembly line balances that were obtained for this illustrative problem are shown in the graphical form, Figure 1. The peaks of the saw tooth

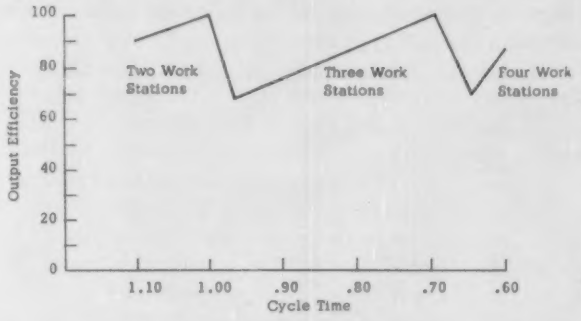

FIGURE 1

graph indicate the points of maximum output for a given number of work stations. When assembly lines are operated at these cycle times, costs per unit of production are lowest on that line.

AN ALTERNATIVE APPROACH

The technique just discussed has the ability to find alternative solutions to the assembly line balancing problem. These alternative solutions are not necessarily improvements over the original set of solutions, but the alternative set provides a simple and convenient means of testing to see whether better solutions are likely to exist or not. The alternative set of solutions is calculated using the "inverse positional weight." This "inverse positional weight" is obtained by looking at the assembly operation from the end of the line to the start of the line rather than the more conventional method of looking at the line from the start of the line to the end of the line. The precedence matrix illustrated earlier has all the information necessary for inverse positional weight calculations. The calculations are made by summing the work unit time with the work unit times of all work units indicating a "+1" in the *column* of the specified work unit, rather than in the *row* as was done previously. The bal-

ances obtained by this method will list work units in the inverse order to the actual order of performing the work. Again using the sample problem, the following calculations illustrate the method.

work unit time	*work unit*	*precedence from column 10 of matrix*	*inverse positional weight*
0.32	*00*	1	0.32
0.10	*01*	1	+0.10
0.20	*02*	1	+0.20
0.05	*03*	1	+0.05
0.10	*04*	1	+0.10
0.23	*05*	1	+0.23
0.20	*06*	1	+0.20
0.05	*07*	1	+0.05
0.32	*08*	1	+0.32
0.10	*09*	1	+0.10
0.30	*10*	0	+0.30
			1.97

Having calculated all other positional weights in a similar manner, and having sorted them in descending order of positional weight, the following listing is obtained:

sorted work units	*inverse positional weight*	*immediate inverse precedence*	
10	1.97	—	
09	1.67	*10*	
08	1.52	*09*	
06	1.05	*08*	
07	0.90	*09*	
05	0.85	*06*	*07*
02	0.62	*05*	
00	0.32	*02*	
04	0.25	*08*	
03	0.15	*04*	
01	0.10	*02*	*03*

Try cycle time = 1.00

Work Station 1		*Work Station 2*	
work unit	*cumulative station time*	*work unit*	*cumulative station time*
10	0.30	*05*	0.23
09	0.40	*02*	0.43
08	0.72	*00*	0.75
06	0.92	*04*	0.85
07	0.97	*03*	0.90
		01	1.00

By using the inverse positional weight for work units, a two station balance was again obtained with a cycle time of 1.00. This is no improvement over the balance obtained by using the forward positional weights. However, the inverse positional weight calculation did generate a new balance as shown in the detailed sequence of work unit assignment. The work station content, however, is identical with that of the first balance obtained in the illustration.

SUMMARY

The technique discussed in this article presents another approach to solving the assembly line balancing problem. While it is true that the technique does not guarantee optimal solutions, the logic provides for simple and economical computer manipulation. This makes it possible to test many alternative balances in a very short time, and gives the methods and time standards man an effective tool for examining the characteristics of his assembly lines under a variety of conditions. The understanding generated will point the way toward better balances, perhaps improving upon the computer generated balances, and also toward more flexible product and facilities design as attempts are made to reduce technological restrictions present on the line. This will assure more economical operation of assembly lines.

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The Origin and Significance of Perceptron Theory[1]

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ONE of the greatest mysteries of nature is the principle by which the human brain functions. For hundreds of years man's attempt to gain understanding in this area has been frustrated to the point of exasperation. Within the last few decades, however, it is apparent that progress has been made. Many researchers are now coming to believe that enough is known to permit the development of useful automata based on simplified models of the brain. It is the purpose of this article to present an appraisal of one of the newest and most promising brain models, the perceptron, in its proper perspective to the work which has preceded it and to the known properties of the brain.

The significance of perceptron theory to the Industrial Engineer stems from the probable future development of a new family of versatile automata which might well come to play an exceedingly important role in the implementation of advanced industrial systems. Furthermore, the mathematically inclined reader will doubtlessly find perceptron theory a stimulating intellectual challenge.

PRELIMINARY CONCEPTS

In the following discussion, a simplified review of a few of the salient features of the brain will prove useful in evaluating the plausibility of various brain models.

The human brain is composed of about ten billion neurons, each of which is a single cell capable of emitting an electrochemical impulse when suitably excited. They are essentially all-or-nothing devices which fire when their threshold is exceeded (that is, the incoming excitatory impulses are sufficiently greater than the inhibitory impulses) and are inactive otherwise. There are three types of neurons distinguished in the brain: the sensory neuron which receives all input messages from the various sensory receptors, the motor neuron which sends output messages from the central nervous system to glands and muscles, and the internuncial or association neuron which is responsible for everything which goes on between the input and the output. There are about one hundred times as many association neurons as there are sensory or motor neurons. Each one receives impulses from many other neurons through its input conductors and in turn stimulates other neurons through elaborate ramifications of its output conductor. The connections between nerve cells are known as synapses, which have the important property of allowing impulses to pass in only one direction. Incoming messages elicited by stimuli impinging on the organism are thus greatly amplified and spread throughout the brain.

Since each of the approximately ten billion cells may be connected to hundreds or thousands of others, it is clearly a hopeless task to enumerate the complete logical structure of the brain. Indeed, only the gross organization is known. The input and output mechanisms are fairly well described, but the big question still remains concerning what goes on between the input and the rather amazing output. The immense number of connections strongly suggests that not every one is specified genetically. Many, if not most of them, are the result of the organism's experience, or are determined by chance subject to certain parameters of growth.

One of the many phenomenal faculties displayed by the brain is *perceptual generalization*, which is the ability to recognize members of classes of objects in various positions, sizes, shapes, angles, and orientations, even if a new configuration is presented for the first time. Consider the image of a man, for example, and the variety of shapes he may assume as he moves. An observer is usually able to perceive a "man" no matter what view he sees. Clearly, the brain must develop some concept of similarity which enables it to perform the generalization involved here. In other words, nonidentical stimuli may be perceived as belonging to the same class when this is justified by the organization of the stimulus world.

An important concept concerning memory is *equipotentiality*, which means that memory and many of the higher order functions of the brain appear not to be localized in any particular spots, but rather are diffused throughout the cerebrum (the upper and frontal part of the brain, which is highly developed in man and is concerned with voluntary and conscious mental processes). There appears to be no neuroanatomical evidence for any special storage organs used for memory. A remarkable experimental fact which illustrates this notion is the ability of the brain to withstand the removal or destruction of substantial portions of the cerebrum apparently without serious effect. The harm of extirpation seems to appear as a partial across-the-board reduction in memory and higher order functions, rather than the loss of particular memories or faculties. Somehow the unremoved parts are able to take over many of the functions of the removed parts.

[1] Based upon a presentation to the graduate seminar in Industrial Engineering at Cornell University.

THREE CLASSES OF BRAIN MODELS

With the previous remarks in mind, one is in a position to review briefly three important classes—not meant to be mutually exclusive—of brain models: physiological, symbolic logical, and self-organizing. An understanding of them is essential to an appreciation of the background from which perceptron theory has arisen.

Physiological models generally strive to incorporate specific physiological and psychological information into a qualitative theory. The primary concern is with the biological nervous system and its interactions with its environment rather than with the development of formally analogous machines. D. O. Hebb, at McGill University, is an influential leader of this school, and has set forth his views in an important book entitled *The Organization of Behavior*. One of his main tenets is as follows (3):

> When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth or metabolic change takes places in one or both cells such that A's efficiency, as one of the cells firing B, is increased.

From this very appealing postulate he proceeded to construct a rather complete theory of learning, perception and memory. Unfortunately, however, the model is verbal and qualitative, and therefore gives no definitive description of how a real system could be made to work in the manner described.

Although tending to be preoccupied with neurophysiological detail, and hampered by a lack of analytical mathematical description and empirically testable hypotheses, members of this school have furnished many invaluable ideas which have found incorporation in the theories of other modelists. Their work has had the important effect of assuring a greater degree of biological and physiological plausibility in succeeding models than might otherwise have been the case.

Symbolic logic models have their foundations in Turing's famous paper on computability (13), and the ensuing confidence that any computable function can be computed by very simple devices. With the advent of digital computers and switching theory, many mathematically inclined researchers were struck with the seemingly great resemblance of the computer and the brain. This resemblance is, of course, a result of the computer's ability to perform a complex series of logical algorithms upon symbolic data—an ability hitherto monopolized by humans—and also due to the striking similarity of the neuron and the basic switching elements of the computer.

Inevitably, models were proposed which were merely logical contrivances designed to perform particular algorithms in response to sequences of stimuli. These algorithms were ingeniously devised to imitate certain aspects of the brain's function. The logical contrivances employed were collections of idealized neurons, which amounted to "and," "or," and "not" gates. A good example is the McCulloch and Pitts nerve nets (5), which were shown to be capable of a wide variety of brain-like (the term is used loosely) functions.

In recent years, interest in this type of model has waned on the part of those who prefer not to wander very far from the known biological properties of the brain. The knell is sounding for this school by a general lack of biological plausibility:

1. Extirpation of any part of such nerve nets would destroy their function.
2. Many more than ten billion neuron-like units would usually be necessary to accomplish even modest feats.
3. The specificity of the connections required would appear to violate any reasonable assumption as to the amount of genetic information transmitted through heredity.
4. Symbolic logic models are usually not adaptive enough for general purpose learning and behavior.

The late John VonNeumann focused his mathematical genius on this approach during his last months in a penetrating little book, *The Computer and the Brain,* published posthumously in 1958. Although a staunch advocate that man might some day construct an artificial device working on the same principles as the human brain, he pointed out that the central nervous system is characterized by such low logical and arithmetic depth that its mathematics" must structurally be essentially different from those (mathematical) languages to which our common experience refers." He was probably referring to computer-oriented mathematics.

Symbolic logic models are of interest today mainly as an approach to the construction of special-purpose machines such as character-recognition devices. Although they illuminate the logical nature of some of the problems associated with the brain's function, their organization is usually quite remote from that of the real thing.

Self-organizing or adaptive models represent a reaction to the determinism of the computer-like symbolic logic models. Whereas computers can make decisions based on logical rules and may be coupled to systems so as to exert control over them, the brain adds at least one other important capacity: the ability to interpret and learn from its environment. Advocates of self-organizing models emphasize that no system with a completely predetermined logic can spontaneously improve its ability to perform useful functions. The attempt to build such a system usually proceeds along one of two lines: the system's organization may be allowed to hunt at random or systematically through many possible states until a state is found which achieves the purpose at hand, or its organization may be modified in a methodical way on the basis of repeated exposures to its environment in order to "learn" to perform some useful task.

An example of the former approach is Ashby's homeostat, which is concerned with the maintenance of a stable state within the system, rather than with the representation of meaningful information (1). An example of the latter approach is Uttley's conditional probability machine, which develops class relationships among stimuli

on the basis of the conditional probabilities of their joint occurrence during the experience of the system (12). It is characteristic of many of the models of this type that they are fairly well-defined mathematically, and some are more reconcilable with the biological facts of life than are the symbolic logic models.

Dr. Frank Rosenblatt, working first at Cornell Aeronautical Laboratory and now at Cornell University as Director of the Cognitive Systems Research Program (all the while under O.N.R. sponsorship), has founded what is considered by many to be the most promising new model of this school of thought, the perceptron. Perceptron theory addresses itself to the problems of learning, discrimination, perceptual generalization, and memory. Its goal is to specify a biologically plausible and mathematically rigorous device which will be capable of reorganizing its own logic after exposure to the logical organization which already exists in the universe around it. Please note that at no time is any suggestion made that the perceptron may think; the author is not willing to invite the polemics which would surely follow such an ambiguous statement.

THE SIMPLE PERCEPTRON

The perceptron is a minimally constrained artificial nerve net consisting of logically simplified neural elements, called *Rosenblatt neurons*, arranged in a manner organizationally similar to the mammalian visual system. Its detailed wiring diagram may be determined essentially at random, subject to certain parametric constraints. There are many different *classes* of perceptrons, depending on the particular organization and dynamic rules of operation specified. A simple and well-understood class is the *simple perceptron*, familiarity with which is essential to an understanding of the more advanced classes.

THE ROSENBLATT NEURON

The Rosenblatt neuron is a device which generates a signal of unit value if the algebraic sum of its input signals is greater than some arbitrary *threshold*, called θ. There may be any number of simultaneous input signals, each of which may be positive (excitatory) or negative (inhibitory). From these discrete logical elements, then, which fire or do not fire according to whether or not their threshold is exceeded, one may construct various classes of perceptrons.

ORGANIZATION

The simple perceptron is organized in the serial manner indicated in Figure 1. Three kinds of logical elements, hereafter called *units*, are distinguished: *S-units* (sensory), *A-units* (association), and *R-units* (response). The A and R-units are Rosenblatt neurons, and the S-units are devices for generating a signal from stimuli (for example, photocells). The *stimuli* may consist of any distribution of energy to which the S-units are sensitive. Any given set of stimuli defined on a collection of

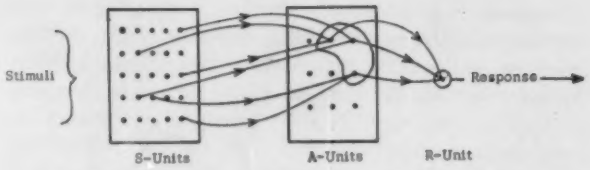

FIGURE 1. Organization of a Simple Perceptron.

S-units is known as the *environment*.

The S-units may be thought of as corresponding to the retinal projection on the visual cortex (that part of the cerebrum which receives topologically preserved images from the retina), the A-units to a layer of association neurons, and the R-unit to a motor neuron in the motor cortex (that part of the cerebrum which is responsible for initiating muscular movement).

The connections between the S-units and the A-units are random, the only condition being that X excitatory and Y inhibitory connections must be made to each A-unit. X and Y are therefore design parameters. The origins of these connections are usually chosen according to a uniform probability mass function over the S-units. Note that connections are unidirectional, from S to A and A to R in the simple perceptron. Feedback is permitted in some of the more advanced classes, but not in this one. There is one A to R connection for every A-unit, and all A-units have the same threshold θ. Each *connection* takes on a *value*, which may be thought of as an amplification factor applied to the input signal to the connection. The values of the S to A connections are fixed, and do not change with time. Without loss of generality, they may be considered to be plus or minus one for excitatory and inhibitory connections respectively. The values of the A to R connections, however, may increase or decrease according to some dynamic training rule, as will be discussed later. These values are crucial, for they constitute the memory of the system. The *memory state* of the system is said to be the collection of the values of all the connections at a particular time. One challenge of perceptron design is to devise rules of learning so as to eventually give a combination of values such that the desired *responses* (the firing or not firing of the R-unit) accompany the showing of the stimuli defined for each problem.

THE EXPERIMENTAL SYSTEM

The simple perceptron must learn to identify each of a given set of stimuli as belonging to some class which has been chosen by the investigator arbitrarily or otherwise. To achieve this goal, the simple perceptron requires a teacher known as the *Reinforcement Control System* (abbreviated RCS) which is *not* a part of the perceptron proper. The function of the RCS is to decide when to reinforce the perceptron by changing the values of its connections, and hence its memory state. The RCS may be a human being, a computer, or even another well-trained

perceptron. It performs this function by monitoring each stimulus and the corresponding response of the perceptron, comparing these with a truth table which lists the desired responses for each stimulus, and then changing the values of the appropriate connections as dictated by a particular simple iterative *training rule*. Training might be thought of as rewarding a perceptron when it is right, or punishing it when it is wrong. After repeated trials the machine will, hopefully, learn its lesson. Figure 2 indicates how the experimental system is arranged.

In evaluating the performance of a simple perceptron, a standard learning experiment is customarily used. First, the design parameters are chosen—the number of S-units, the number and threshold of A-units, the number of excitatory and inhibitory connections per A-unit, the training rule to be used, the set of stimuli and the desired responses thereto. Then the values of all connections are set to zero, and the perceptron is shown a training sequence of stimuli. After each showing, the RCS modifies the values of the connections in accordance with the chosen training rule. Upon completion of the training sequence, the perceptron is shown one or more test stimuli; and its ability to correctly identify the classes of these stimuli is noted. More training sequences are shown, without resetting the values to zero, until perfect performance is achieved, an asymptotic level is reached, or the experimenter decides to terminate the experiment. The measure of performance is usually the probability of selecting a perceptron with given parameters which will correctly identify all of the test stimuli for various numbers of training exposures. Please recall that it is proper to speak of probabilities here because once the parameters are chosen, the actual connections and stimuli may be chosen at random.

SOME RESULTS

There are four general methods of determining the operating characteristics of a given perceptron. One may give a heuristic argument, conduct a simulation experiment, build a hardware device, or use rigorous mathematical analysis. All of these methods have made important contributions to perceptron theory. The author regrets that space does not permit the inclusion of mathematical proofs of the results given here, and strongly urges the interested reader to obtain the necessary references, particularly (2) (4) (9) (10).

The simple perceptron may be trained to associate an arbitrary set of responses with an arbitrary set of stimuli if it has enough A-units and a sufficient number of learning trials. And if it has seen a large enough representative sample of each group of "similar" patterns, covering all parts of the retina, it will learn to recognize an arbitrarily positioned stimulus which it has not seen before. This generalization is largely limited, however, to stimuli which have considerable retinal overlap with members of the same class and little overlap with members of the opposite class.

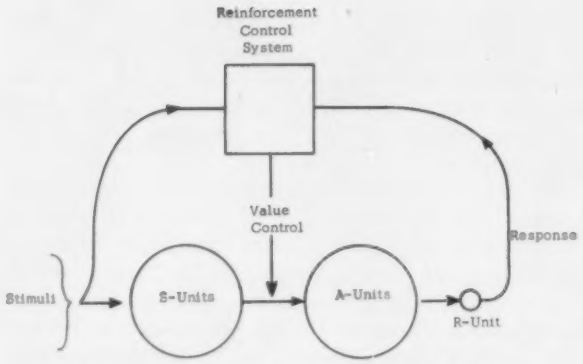

FIGURE 2. Experimental Systems with a Simple Perceptron.

More precisely, it has been rigorously proved (2) that a simple perceptron using an *error correction* reinforcement rule will always arrive at a solution to a discrimination problem in finite time, provided only that some solution exists and provided that each stimulus in the environment recurs in finite time. The error correction reinforcement rule dictates that the values of the A to R connections not be changed at all if the response is correct, but each time the response is wrong then the values of the active A to R connections (those which fire upon presentation of the stimulus) are incremented by a small fixed amount. The inactive connections are left alone. Many other reinforcement rules have been explored, but error correction is the most efficient one yet known for general use.

This is one of the most important theorems proved to date, for it guarantees that a simple reinforcement rule is sufficient to enable a randomly connected simple perceptron to organize itself usefully on the basis of its own experience. All it needs to be told, essentially, is whether it is right or wrong.

A MORE ADVANCED PERCEPTRON

The simple perceptron described presents an excellent introduction to the more complex classes of perceptrons, whose behavior is frequently much more interesting. The basic assumptions and approach remain unchanged, but different organizations and rules of operation are explored. For example, nearly all of the more advanced perceptrons use many R-units rather than a single one in order that multiple responses may be provided for. The four-layer series-coupled perceptron will now be briefly introduced to illustrate one kind of behavior which interests researchers.

As may be seen in Figure 3, this class of perceptron uses two layers of A-units instead of one. The second layer is in one-to-one correspondence with the first layer of A-units. Whereas the S to AI and AII to R connections may be random, each AI unit is connected to every AII unit. All associators have a common threshold θ.

Subsequent to the showing of a stimulus, each active AI unit sends a signal equal in magnitude to θ to its

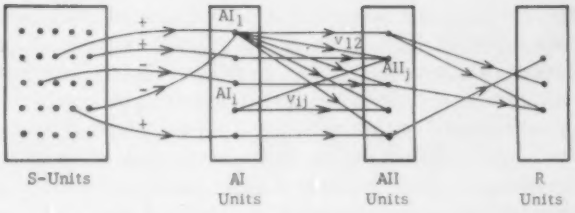

FIGURE 3. Organization of a Four-Layer Series-Coupled Perceptron.

corresponding *AII* unit and also a signal v_{ij} to every other *AII* unit. The values of v_{ij} are initially zero, but change according to the following rule. If AI_i is activated by a stimulus which is the next one to be shown after a stimulus which activates AII_j, then the connection v_{ij} is incremented by a fixed amount; otherwise it is not incremented. Simultaneously, the other connections are decremented by a proportional amount. This rule amounts to a facilitation of used connections and the decay of unused ones. Note that the experimenter does not need to do anything to the perceptron except show it the stimuli. No RCS is necessary.

The four-layer series-coupled perceptron is capable of organizing itself upon exposure to an environment which is organized with temporal contiguity, and of generalizing responses from one stimulus to another. More specifically, an experiment may be carried out in which random sequences of letters are shown in such a way that each letter is more likely to follow itself in the sequence than a different letter. Each letter may be shown in different positions or in various styles each time it occurs. Such a training sequence provides the necessary temporal contiguity of the environment. After a number of exposures, the perceptron will develop a different response to each letter in the sequence—one response for the *A*'s, another for the *B*'s, and so on. Of course, the experimenter can't predetermine the desired responses for each letter unless he reinforces the *AII* to *R* connections, an action which this experiment disallows in order to demonstrate the remarkable ability of the perceptron to organize itself spontaneously with no outside help (2).

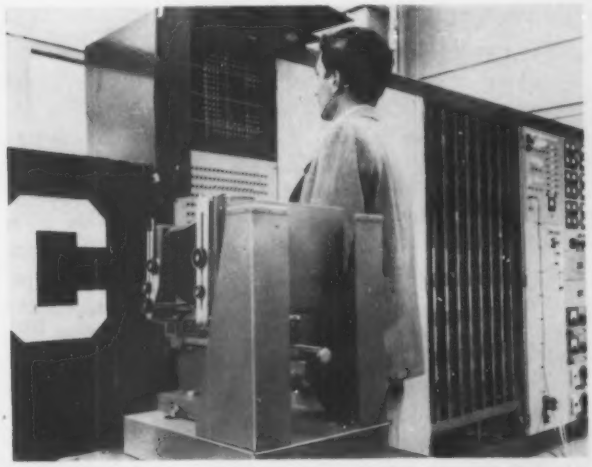

FIGURE 4. Overall View of a Mark I Perceptron Looking at a "C".

CURRENT STUDY AND APPLICATIONS

A great deal of work, much of it consisting of mathematical analysis complemented by computer simulations, is currently under way. Only a few of the active areas are mentioned here.

There is continuing interest in the construction of hardware perceptrons, which are useful research tools. The first and so far the only working perceptron is known as Mark I (Figure 4). It consists of 512 *A*-units, 8 binary *R*-units (notice that this multiplicity of *R*-units takes Mark I out of the category of a true simple perceptron), and 400 *S*-units. The retina of *S*-units is a 20 by 20 array of photocells positioned in the film plane of a view camera to which the stimulus pictures are shown.

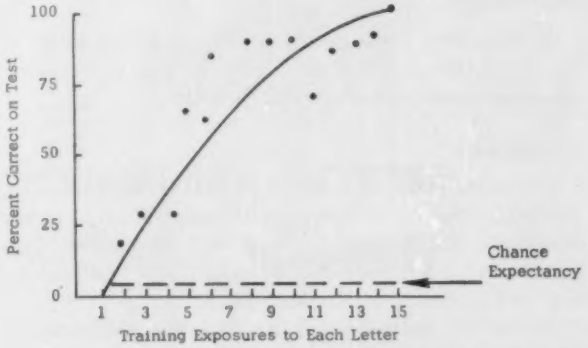

FIGURE 5. Mark I Learning Curve for 26 Letters, Each in Standard Position, Error Correction Training.

The values of the *A* to *R* connections are changed by motor-driven potentiometers, and the origins of the *S* to *A* connections are drawn from a table of random numbers. Experiments with Mark I have substantiated the conclusions previously obtained from analytical work and simulation experiments. One particularly interesting result, for example, showed that in an *E-X* discrimination experiment removal of half of the *A*-units reduced performance from 100 percent to 98 percent, and the removal of seven-eighths of the *A*-units reduced accuracy to 80 percent. This may be interpreted as concrete evidence that memory is distributed in the perceptron, thus conforming to the observed equipotentiality in man and other animals. Another *E-X* discrimination experiment designed to explore the effects of trainer error, in which the RCS gave the right corrections only 70 percent of the time, revealed that the perceptron was still able to achieve perfect or near-perfect performance after about 20 training exposures per letter. As a final illustration, Figure 5 shows that about 15 training exposures to each letter were necessary to enable Mark I to identify them

all correctly when shown in standard position.

Construction of a phono-perceptron, Tobermory, (one which responds to an audio input) is just beginning. It is a speech recognition system whose objective is to be able to recognize words spoken by anyone. It will probably use about 12,000 *A*-units in three layers and have a fairly limited vocabulary at first. Completion is scheduled for a year from now.

A-units are the object of several study groups. Several solid-state and liquid-state devices hold promise of providing inexpensive, efficient, compact substitutes for the cumbersome electromechanical assemblies used on Mark I.

Another interesting study concerns the problem of identifying nuclear events in bubble chamber photographs. Bubble chambers are devices which allow study of the nuclear effects of charged particles. The aim is to train a perceptron to pick out certain rare events from the thousands of photographs produced by these devices.

EVALUATION

It is evident that perceptron theory avoids many of the pitfalls of earlier brain models, both as to biological plausibility and methodological approach.

PLAUSIBILITY

Equipotentiality of memory has been clearly demonstrated by the extirpation experiments of Mark I, as was noted above. The perceptron is one of the very first models, if not the only one, which exhibits this remarkable and important accomplishment.

Perceptual generalization, which is the ability to see similarities between nonidentical stimuli, appears to have been only partially attained by simple perceptrons, but has been impressively demonstrated by the four-layer series-coupled perceptron. The former device develops a notion of similarity on the basis of spatial contiguity, the latter on the basis of temporal contiguity. Since the real world exhibits a high degree of spatial and temporal contiguity, the usefulness of such machines seems assured.

Learning in the simple perceptron requires the services of the Reinforcement Control System. It is legitimate to question the plausibility of such a scheme in nature. Could it be a teacher whose influence on the values of the connections is effected by the stimuli which it imposes on its student? Is it another center or part of the brain which assumes this relationship? The concept of a teacher is plausible, but the manner of its influence is still open to question. Fortunately the absence of a RCS for the four-layer perceptron and other advanced classes mitigates the importance of this question.

The amount of information necessary to specify the organization of a perceptron is very much less than that required to specify a comparable symbolic logic machine, even if one with the same capacities for general purpose learning could be designed. The reason for this is that there is an immense number of particular logical configurations which may suffice to do a given task or set of tasks. Although it is possible to write a complete logical equation for a trained perceptron describing the set of all possible states of the system as a logical function of the set of all possible inputs, it is vastly more efficient to specify only the organization of a nascent perceptron as long as that organization will produce a device with the desired properties after training. Specification of the gross organization and the statistical parametric constraints is well within known limits of the capacity of genetic transmission, whereas complete detailed specification may not be. Another consequence of this approach is that the model is quite neuro-economical. Numbers of *A*-units required for interesting behavior are typically in the thousands. Considering that the human brain uses about ten billion neurons, perceptron requirements seem reasonable indeed. Furthermore, neither the reliability nor the precision of the components is particularly important, as is the case with symbolic logic models. It is interesting to note how this fact differs from the problems of reliability engineering usually found in the design of complex systems.

The Rosenblatt neuron is certainly not a very demanding simplification of the biological neuron. If anything it is too simple, and could be made considerably more complicated without violating known facts. A more important question of plausibility concerns the value functions of the connections between neurons. No conclusive evidence has yet been found which indicates that this assumption of perceptron theory has a physical embodiment in the brain, although the circumstantial evidence is overwhelming for some such mechanism. Indeed, there are many known physical effects which may suffice to provide different values for the connections. For example, synapses—the terminals through which impulses travel from one cell to another—are believed to become more efficient with use and less so with inactivity.

METHODOLOGICAL APPROACH

The careful consideration of biological facts in the assumptions of perceptron theory coupled with the use of rigorous mathematical analysis has led to a fusion of the advantages found in both the physiological models and the symbolic logic models.

For example, perceptron theory is verifiable. Through mathematical analysis and computer simulation it is relatively easy to find out whether or not a perceptron design will do what it is supposed to do. But the question of whether the perceptron does in fact correspond to the human brain is not so easy to verify at this time. The final answer is still a long way off. One must be cautioned not to confuse a little circumstantial evidence with direct proof.

The idea of a standard learning experiment is an important one. It permits the evaluation of different sys-

tems by measures of their performance in perceptual discrimination and generalization after a well-defined training period. This approach is radically different from hunting for memory traces in the association units. Instead, the system's choice of response is the criterion for judging whether or not a concept has been formed.

One of the prices paid for the other advantages of redundant cell usage is the limitation regarding the precision with which a perceptron may be expected to approach being right all the time after its training sequence. Although the probability of error may in many cases be made arbitrarily small by a sufficiently long training sequence and by using a sufficiently large number of associators, in practice one must be willing to accept a finite approximation to error-free performance. But this is hardly surprising, since even we humans are not always infallible.

CONCLUSION

It is evident that developments are still at an embryonic stage compared with what will be necessary for the construction of economical and useful devices. Yet in view of the progress which has been made in the past few years by perceptron theory, there is every reason to be optimistic about the future. One can easily imagine perceptrons scanning military intelligence photos or work sampling photos, and feeding the resulting data into digital or analog computers. Other machines may inspect materials and parts in industrial plants and initiate the appropriate actions. Perceptrons which read handwriting or understand the spoken word will make fine data-acquisition systems; other sensory modalities will extend their usefulness even further. One's imagination rapidly runs rampant among the many possible applications of perceptron theory, to say nothing of the benefits to be derived from increased understanding of the human brain. Let us hope that our dreams will be realized within a reasonable time.

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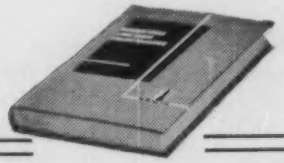

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Sampling to Determine Price Break Advantages in "C" Stock Items[1]

by **J. WILLIAM GAVETT**

Department of Industrial and Engineering Administration, Cornell University

THE APPLICATION of sampling procedures in industrial accounting has been extended in the past decade as an aid in auditing, estimating inventory values, determining product demand characteristics, job costing, etc. In many cases sampling offers the advantage of obtaining a greater scope of information for less cost than is otherwise possible. Furthermore, provided the sampling procedure is carefully designed and executed, the reliability of the estimates obtained may be stated with some known precision and confidence.

The following proposes the use of sampling to obtain an estimate of savings resulting from large lot purchasing of low valued items for stock. The procedure advocated has been tested in a small firm, resulting in a savings from price breaks due to large lot buying of these items.

"C" ITEMS IN STOCK

It is a fairly well established fact that most inventories of purchased materials and supplies can be categorized according to the relative contribution of each item to the total value of inventory or to the total value of material usage during a year. Figure 1 is a familiar expression of this classification which says that a relatively small number of items, Class A, account for a large proportion of the usage or inventory value of all items stocked. Class B items account for a less significant proportion of value, while Class C items account for the least value and yet comprise the largest proportion of items in stock. A principle related to this configuration is that the amount of control exerted on various stock items should bear some direct relationship to their relative value. Control includes both the problems of maintaining up to date information on the items as well as determining economic purchasing quantities and reorder points.

Under this theory it suggests that there is little payoff in examining in detail each of the items included in the C classification. Presumably some general policy is set to cover most or all C items. Such a policy might state, for instance, that all C items are to be purchased in quantities equal to a quarter year's supply. Or there may be no general policy and each item is purchased in some reorder quantity which reflects an initial decision made at the time the item was introduced in the plant. The implication, in any event, is that it is uneconomical to attempt to determine economic purchase lot sizes for each of these C items. That is, if there are, say, 1000 items constituting the C class the determination of price breaks and holding costs for each item would appear to be a major task for the accountant.

In spite of their relatively low value there is still a basic question concerning possible savings involved in giving more than casual attention to these C items. Is there some general policy that would result in an economic ordering of these items without reverting to a close examination of each item? A sampling plan that might shed some light on this question is proposed as follows.

ECONOMIC PURCHASE QUANTITIES

The determination of economic ordering quantities typically considers a balance between the costs of acquisition and the costs of holding an inventory. In many small and medium sized plants the critical variables in the decision are the factors of price break in quantity buying on one hand and capital requirements necessary to support an inventory on the other hand. The costs of preparing purchase orders and the costs associated with physical storage (space, heat, light, etc.) may be minor compared to the first two factors. That is, they may be inescapable with respect to the range of variation in quantities purchased.

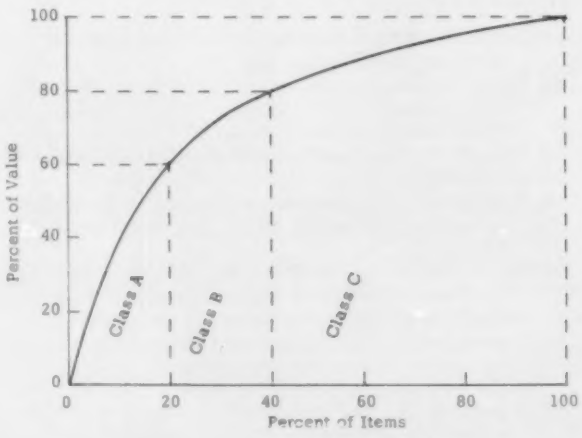

FIGURE 1

[1] Supported in part by Small Business Administration Research Grant.

INSTITUTE INTERESTS

Individuals, chapter officers, institute officers and others are invited to become primary reporters and send in interesting highlights on local, national and international events. The principal criterion is that the item be current and of general interest. Since publication space represents an investment of your funds, please help us avoid "wordy stories." Material can best be handled if it is typed and double-spaced. Pictures to accompany these notices—or just good pictures with explanatory notes are welcomed. Send the material to Professor Wilson J. Bentley, School of Industrial Engineering and Management, Oklahoma State University, Stillwater, Oklahoma. If you forget this address, send it to the JOURNAL *office in Atlanta, and I will get it.*—EDITOR.

AIIE GENERAL NEWS

Since last reported in this section, there have been three new chapters officially recognized. They are: Madison, Wisconsin (115), Richmond, Virginia (116), and Augusta, Georgia—Aiken, South Carolina (117). More are on the way!

* * *

Another reminder that, effective October 2, 1961, AIIE's office will be located in the new United Engineering Center. The address and telephone number will be:

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* * *

President Jack F. Jericho has formed and appointed a new group which will be called the "President's Advisory Council." This move was at the suggestion of Morley H. Mathewson, Vice President of Professional Services and Planning. The purposes of the Council have been developed as follows:

1. Enable the American Institute of Industrial Engineers to pay special honor to a selected group of leaders in Industry, Education, and Government, who were actively engaged in Industrial Engineering, or who had, at sometime in the past, been associated with the profession.

2. Provide a means of recognizing some of the top Industrial Engineers in the country and bring to the Chapters' attention the fact that many leaders in the profession are actively interested in the Institute and its affairs.

3. Provide a service, in an advisory capacity, to the President to assist him in establishing some of the long-range objectives of AIIE.

4. Act as a sounding board for the President on some of the major problems currently facing the Institute and our profession.

5. Perform special tasks for the Institute President as needed.

These objectives were reviewed with Alex W. Rathe and several other leaders closely associated with Industrial Engineering. All of them enthusiastically endorsed the idea of a President's Advisory Council.

The initial meeting was held at an annual dinner at the 1961 Institute Conference and Convention. At this dinner, it was decided to review, informally, many of the problems facing the Institute, and seek the valued opinion of the group on two or three major problems. For example, the need to change the name of Industrial Engineering, which has been proposed in a recent *Journal* article and the need for a second AIIE publication, which is under study by a task force, were discussed at great length. In addition, the question of how the Industrial Engineering profession should cope with the problems being created by automation was carefully considered.

The next step in establishing this council was to seek out a good cross-section of leaders to serve. With valuable assistance from Alex W. Rathe and Morley H. Mathewson, a list of twenty-two names were prepared and invitations sent out to these men to serve on the President's Advisory Council for 1961–62. Affirmative answers were received from eighteen of the twenty-two invitations. Many of those who agreed to serve are well known in the profession, and many of the names will not be new to the membership. The following people are serving on the President's Advisory Council of the American Institute of Industrial Engineers for 1961–62:

Warren E. Alberts, Vice President and Assistant to the President, United Air Lines, Chicago, Illinois.

David F. Baker, Professor of Industrial Engineering, Ohio State University, Columbus, Ohio.

Roger R. Crane, Manager of Management Sciences, Touche, Ross, Bailey, and Smart, New York City, New York.

Merrill M. Flood, Professor and Senior Research Mathematician, Mental Health Research Institute, University of Michigan, Ann Arbor, Michigan.

Lillian B. Gilbreth, Consultant, Authoress, and one of the outstanding leaders in Industrial Engineering, New York City, New York.

Frank F. Groseclose, Head of Industrial Engineering, Georgia Institute of Technology, Atlanta, Georgia.

George H. Gustat, Director of Industrial Engineering, Eastman Kodak Company, Rochester, New York.

Frank J. Johnson, Manager of Producibility Design, Lockheed Aircraft Corporation, Marietta, Georgia.

Paul Lehoczky, Head of Industrial Engineering, Ohio State University, Columbus, Ohio.

Robert N. Lehrer, Chairman of Industrial Engineering, Northwestern University, Evanston, Illinois.

Donald G. Malcolm, Vice President, Operations Research, Incorporated, Santa Monica, California.

Morley H. Mathewson, Director of Industrial Enginering, International Minerals and Chemical Corporation, Skokie, Illinois.

Harold B. Maynard, President, Maynard Research Council, Pittsburgh, Pennsylvania.

John M. Mihalic, Jr., President, Avco Corporation, Nashville Division, Nashville, Tennessee.

Matthew A. Payne, Manager of Purchasing, Lubrizol Corpora-

tion, Cleveland, Ohio.

Alex W. Rathe, Professor, New York University, and Consultant, Thornwood, New York.

Edward L. Slagle, Works Manager, Columbia Geneva Steel Corporation, Pittsburgh, California.

Jack L. Watson, Assistant Vice President—Transportation Services, United Air Lines, Denver, Colorado.

PROFESSIONAL SERVICES AND PLANNING

MOVE TO NEW UEC BUILDING PLANNED

American engineering is quartered in its new home, the United Engineering Center, a 20-story building on New York's east side, between Forty-Seventh and Forty-Eighth streets facing United Nations Plaza.

The 19 major engineering societies and agencies are tenants of the new building. About 650 headquarters personnel were involved in the shift of the offices of the societies, which have a combined membership of more than 300,000 engineers.

All except two floors, the 15th and 16th, are occupied. These will remain vacant for possible expansion of the tenant societies, or be available for other societies desiring to move into the new structure.

The main entrance to the building is on 47th street, and besides an attractive marble-walled lobby, the ground floor has a large auditorium with a seating capacity of 450, an exhibit area of over 6,000 square feet, and a main lounge. A large cafeteria, together with several private dining areas, occupies the lower level.

United Engineering Center

The Engineering Societies Library, often called the most comprehensive engineering library in the world, and Engineering Index occupy the second floor and other sub-floor areas for stacks. These areas are reached with a special elevator.

Occupants of other floors are as follows:

Third floor—United Engineering Trustees, Inc., Engineering Foundation, Engineers Joint Council, Society of Women Engineers, American Institute of Consulting Engineers, Engineers Council for Professional Development, Municipal Engineers of the City of New York.

Fourth floor—American Institute of Industrial Engineers, American Society of Heating, Refrigerating and Air-Conditioning Engineers.

Fifth, sixth and seventh floors—The American Society of Mechanical Engineers.

Eighth floor—Welding Research Council, American Welding Society.

Ninth floor—Illuminating Engineering Society, American Institute of Electrical Engineers.

Tenth and eleventh floors—American Institute of Electrical Engineers.

Twelfth floor—American Institute of Chemical Engineers.

Thirteenth and fourteenth floors—American Institute of Mining, Metallurgical and Petroleum Engineers.

Fifteenth and sixteenth floors—Vacant and unfinished—for future expansion.

Seventeenth and eighteenth floors—American Society of Civil Engineers.

The nineteenth and twentieth floors will be used for mechanical equipment.

Funds for the $12,000,000 building were raised through a member gifts campaign and from industry. Welded steel framing is utilized throughout the building, with exterior walls predominately curtain wall construction. Clear glass and blue-tempered spandrel glass, divided into rectilinear patterns by stainless steel mullions and column sheathing, enclose most of the tower, which houses the offices. Two tower corners and a considerable expanse of base building wall are faced with limestone.

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NEW EDUCATIONAL DEVELOPMENTS SPURRED BY UCLA FELLOWSHIPS

Dean L. M. K. Boelter of the UCLA College of Engineering has announced the creation of a variety of predoctoral and postdoctoral fellowships. The fellowships are a part of the Educational Development Program (EDP), an organized faculty effort directed toward further improvement of UCLA's unified undergraduate program and graduate design and research programs. EDP activities currently include the development of new courses, syllabi, teaching materials and a systems study of engineering education at UCLA.

The fellowships are designed to attract graduate students who are interested in rapidly progressing toward the doctorate in engineering.

Predoctoral fellowships are available up to a maximum of $2,000 per year plus tuition. Combined postdoctoral fellowships and faculty appointments provide a total stipend approximately equal to the salary of a beginning faculty member. There are also opportunities for experienced design engineers who are interested in a combination of teaching and the further study of the discipline of design.

Inquiries may be directed to William D. McIlvaine, Secretary, Educational Development Program, College of Engineering, University of California, Los Angeles 24, California.

PROFITS ARE NOT ENOUGH

HENRY L. GANTT'S HERITAGE TO INDUSTRIAL ENGINEERING*

By ALEX W. RATHE, *Visiting Professor, Graduate School of Business, Columbia University and Past President, AIIE*

Today no one doubts that Industrial Engineering is a mainstay in progressive management. It has not always been that way.

Industrial Engineering is perhaps 75 years old. Management is as old as mankind; it has been in evidence ever since the population of this earth grew from one to two. It exists—is necessary—wherever there is human activity.

Presently management is recognized as being active in all types of human endeavor. The first systematic contributions toward making this immense scope of management workable were made by engineers around the turn of the century. To paint the full panorama of these developments, we need merely mention such names as Frederick W. Taylor, the glorious partnership of the Gilbreths and Henry Laurence Gantt, whose one-hundredth anniversary of his birth, on May 20, 1861, bestows the distinction upon this gathering to be participants in the Gantt Memorial Conference.

Out of these engineering contributions to management developed our branch of the profession, Industrial Engineering. It represents the first use of engineering, not on behalf of a firm's products or services, its facilities or structures, but rather in furtherance of its management.

Like management, Industrial Engineering started with a restrictive scope, namely the production floor, because at its birth date around 1900, production activities caused the largest amount of managerial problems. Industrial Engineering has expanded its concern steadily since then, especially in the last ten or twenty years. Like management, it is now at work in all spheres of human activity:

.. in mining and manufacturing,
.. in wholesaling and retailing,
.. in transportation,
.. in hotels, restaurants and entertainment,
.. in construction,
.. in noncommercial enterprises,
.. in agriculture,
.. in the home,
.. etc.

More important than the changes in the scope of management and of Industrial Engineering are their respective aims. Industrial Engineering aims are management's aims. And it was Henry L. Gantt who made one of the finest proposals of what the basic essence of these managerial aims should be. He did it with such clairvoyant foresight that today, over forty years after his death, the objectives he set for all of us, still beckon to many of us as a goal for the future.

In an age where accepted habits of life are swept away more speedily than at any other time in recorded history, obsolescence of ideas is staggering. Thus persistent pioneering and staying power of thought indicates robust health; it forecasts vast benefits for the future as well.

Mr. Gantt's idea of management aims is as powerful as it is simple: Management is a leadership function; its mission is progress.

LEADERSHIP AND PROGRESS

Leadership is the key to executive success because management involves the direction of people. Management gets results only through the work of others.

This requires a sizable storehouse of knowledge. Among the areas it helps, there are the

.. developing of objectives,
.. recognising of obstacles on the road to their fulfillment,
.. devising not just of any way but of the one best way to clinch success: (May I respectfully recall the Gilbreths' mandate for a never-ending quest for the One Best Way, to make the best today better still tomorrow. To accomplish this, faith in our own creative capacity and in that of our associates must never fail us. We know what is good enough now won't do any more in the future. We *can* create something better if we set our minds to it. We *must* create something better if we are to mature our engineering opportunities in management.)
.. harnessing of human and material resources,
.. measuring and evaluating performance,
.. search for more knowledge.

Frederick Taylor pioneered the solving of management problems in a scientific manner. Mr. Gantt spelled it out this way: "Scientific investigation is rapidly putting at our disposal vast amounts of knowledge which it is the business of the engineer to utilize for the benefit of the community." This was written in 1911! It explains, in one clear-cut sentence, the relationship between science and engineering which puzzles many people still today.

A few years later, Mr. Gantt elaborated: "The new industrial spirit bases action on what *can* be done, instead of on records of what *has* been done or on opinions of what *might* be done." At the one-hundredth anniversary of the author's birth, a gradually growing roster of testimony reaffirms the soundness of his advice, witness the application of the knowledge of

.. Physiology to problems concerning wage incentives or protective clothing or operating schedules,
.. Psychology and Sociology in matters of performance measures, layout and work assignments,
.. Economics with regard to forecasting,
.. Statistics and Mathematics for a growing number of problems.

Of course, before a man would dare lead other men, many additional abilities and gifts and much more experience are required, such as

.. sound judgment,
.. an extra capacity for making decisions,
.. character,
.. initiative and drive,
.. sensitivity to the reactions, opinions and feelings of others.

Again the Gantt genius pointed out the road we have to travel: "The general policy of the past," he said, "has been to drive; but the era of force must give way to that of knowledge. The policy of the future will be to teach and to lead." In deep respect, the American Institute of Industrial Engineers chose this thought as the cover statement for its Annual Report this year.

Leadership in a free society is a means to an end, not an end in itself. What is its objective? Mr. Gantt's suggestion is straightforward: Management must promote progress.

Rough as competition may have been on some of us just recently, it will become fiercer still in the future. The days of the easy order-taking are over. In a world which has shrunk under the rapid advances of transportation and communication, imports of products and of ideas into our country are likely to be even easier in years to come. On the other hand, exporting our goods and our convictions will meet with increasing barriers in other nations. We have to run fast in order just to stay even with the field.

Yet can we claim leadership if we just remain where we are? Is not the essence of leadership its obligation to be ahead, to move ever farther out in front? This means progress—more progress—faster progress. Should progress lag, the only alternative would be

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* *In response to widespread requests, highlights of Dr. Rathe's keynote address to the Twelfth Annual Conference are presented.* —EDITOR.

resignation to a status quo; but that is merely the first step to decline and to ultimate oblivion. Conversely, progress means innovation.

The Supreme Power has given us a mind to think and a heart to be conscious of human reaction. Who dares impose man-made limitations upon this God-given capacity to create as long as such innovations generate economically and socially lucrative results.

To make progress even one infinitesimal stitch, takes the best that has been placed within us. It is most fortunate that to increase the utilization of this, as of any other, resource, has been one of the prime objectives of Industrial Engineering from the first day of its existence.

PROFIT—LIFEBLOOD OF THE ECONOMY

To enable Industrial Engineering and thereby management to make progress, we are indebted to Mr. Gantt for a richly stocked arsenal of managerial techniques and thoughts. As engineers, not just as Industrial Engineers, our mind immediately turns to those by which we can help improve economic efficiency. This is the way Mr. Gantt felt on the subject: "Our main problems are still to till the soil to the utmost possibility, to run our idle machines to their utmost capacity, and to make producers out of that vast army of present-day busy people whose energies are wasted in upholding an inefficient system." Can we honestly claim that these problems have been solved today, sixty years later?

The reward for utilizing our resources ever more intensely is profit, the economic lifeblood of a free enterprise system. To dispute the need for profits was utter nonsense to Mr. Gantt as it is to us; it seemed to him tantamount to doubting the basic facts not only of economic but also of human life.

On the contrary, not to make a profit is a crime because it endangers the organization. Lack of profit threatens owners and employees with the ultimate loss of their investment and their livelihood. Without a question of a doubt, profit is one of the indicators that progress *is* being made. But to believe that only profits count, is wrong. Industrial Engineers and managers owe to Henry L. Gantt the recognition that profits are not enough because profits are only an economic measure.

"THE HIGHEST OF DISTINCTIONS IS SERVICE"

Progress demands additional accomplishments. Without them, glittering financial successes are merely misleading milestones; they blind us to the destination of the road which leads inevitably to an ignominious end.

Even now, more than forty years after Mr. Gantt's death, we are only beginning to understand the full meaning of this companion which profits need to insure lasting progress. The clue seems to lie in the fact that managers and Industrial Engineers are always concerned not only with economic success but with social results as well. What then is the mark of social achievement? May I again refer to Mr. Gantt who suggested that "reward according to service rendered, is the only foundation on which industry and business can permanently stand. It is a violation of this principle which has been made," he concluded, "the occasion for Socialism, for Communism, and for Bolshevism."

A characteristic objective for any profession, "service" is a newer term in business. But it is an age-old anchor point for such basic tenets of our nation as are laid down in the Magna Carta or the Declaration of Independence.

Service contains the obligation to hold, also in business, the truths self-evident that "men are endowed by their Creator with certain inalienable rights, that to secure these rights, governments are instituted." This magnificent thought applies to business because managing certainly has aspects of "governing." Service encompasses the managerial responsibilities to the individual and to the groups who are within management's orbit—employees and owners; customers and vendors; the community, locally, nationally and internationally.

Service as the keynote of an enterprise is nothing strange in the free world. Well over fifty percent of the four and a half million businesses in the United States alone are devoted to providing service, for instance

.. transportation, telephone and other utilities,
.. merchandising,
.. finance, real estate and insurance,
.. legal and medical, engineering and other professional undertakings.

I do not mean to imply that every single one of these service organizations always lives up to its avowed purpose in actual operations. Nor do all of those who proclaim profit as their goal; there are lots of nonprofit companies who did not intend to be that way.

In recent years we have also seen a substantial growth of real nonprofit organizations which did not aim at reaping profits; may I merely cite as examples

.. hospitals,
.. private universities,
.. research institutions,
.. development companies,
.. many other nongovernment enterprises,
.. and, of course, government itself.

We need not delve into any specific company history to substantiate the fact that the satisfaction which service brings to those who render it, is *a* widely, perhaps *the single most* widely sought objective of much of human activity. There is not one individual who would have difficulty to recall, as one of the most gratifying moments in his life, some service

.. to friends or complete strangers,
.. to his hometown or some other community,
.. to older folk, handicapped or sick people,
.. to children, be they our own or somebody else's.

But in this group assembled here for the Twelfth Annual Conference and Convention of the American Institute of Industrial Engineers, I can point to a much closer example: The voluntary service to AIIE members—well over ten thousand of corporate grade, several thousands of students, and nearly one thousand of noncorporate grade—by over two hundred and fifty Institute officers and some twelve hundred or so in chapter positions.

Shortly before his death in 1919, Mr. Gantt challenged management: "The business system must accept its social responsibility and devote itself primarily to service, or the community will ultimately make the attempt to take it over in order to operate it in its own interest." This was written before the Securities and Exchange Act was drafted and before government regulations of utilities had started, before the Taft-Hartley Law was in effect and before the idea was propagated that it is up to Washington to write a Code of Ethics for Business.

PROFIT AND SERVICE

A nation—a company—any organized group is a system. Some of its components are economic: raw materials and energy, buildings and machines; others have predominantly social traits such as the development and satisfaction of the people in the system.

These economic and social constituents are interwoven. Many failures of the past (and some of the present, too) go straight back to the lack of recognition of this fundamental characteristic of a system. It was perhaps the absence of what we now call the "systems view" which made engineers and managers tackle, too often and for much too many years, only one factor at a time, then turn to a second, dealing with each separately. When success was secured in one aspect, it was hard, if not impossible, to consider its consequences upon the others.

For example, until not so long ago, things were considered under control as long as profits were satisfactory; under such circum-

stances, little, if any, thought was given to other factors. And if profits lagged, any measure which would pull them up, was believed proper. It most certainly is—as long as its effect upon other aspects of managerial performance is favorable, too.

Can we perhaps sum up that managerial leadership insures progress if its aim is profit and service. We need both, because profit without service is thievery, and service without profit is charity. Management is neither a member of the National Association of Bandits nor of the American Society of Welfare Agencies.

Management is leadership. It means being ahead of others but also being in a minority because only a few can ever be at the top.

But what a minority to be a member of! It is that exclusive group who has as its distinguishing watchwords: reputation and dependability, integrity and courage. It is that select company of men and women whose hallmarks are intelligence and fairness, honesty and vitality, common sense and vision. It is that force whose sound judgment entitles it to make decisions—to stipulate when tradition with all its restraints should take precedence or when more recent experience ought to prevail.

The stature of a progressive leader shows itself in nothing more clearly than in his humility which has taught him that

to be boss means to command;
to command means to serve.[1]

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REPORT ON RESEARCH AND DEVELOPMENT

The Research and Development Organization of the AIIE consists of eleven specialized research directorates and a Research and Development committee. This latter committee carries out a number of activities through subcommittees. The various specialized Directors of Research and their areas of interest are as follows:

Alan J. Rowe—Data and Information Systems
A. H. Rubenstein—Organization Research
Salah Elmaghraby—Production Planning and Control
W. T. Morris—Engineering Economics
John M. Allderige—Work Measurement
Donald Malcolm—Systems Design and Analysis
R. C. Wilson—Facility Planning
L. G. Mitten—Applied Mathematics
R. J. Schreiber—Applied Psychology
E. V. Krick—Methods
George Theuring—Materials Processing

Each of these individuals is well known in his own specialty through his research and writing, and the interest of a group of individuals of the competence and reputation represented by these men augurs well for the future of Industrial Engineering.

The project which currently occupies the group of research directors and their various committee members is admittedly a major undertaking. It is the appraisal of the current state of development of each of these specialized areas so important to Industrial Engineering practice and the preparation of a report in each area indicating the kinds and amounts of research currently in process and suggesting avenues of further exploration or development. These suggested research needs can then serve as the basis for a better understanding of the future trends and be of considerable assistance in defining those problems which collectively provide content, challenge, and concern to Industrial Engineering. A number of the individual research directors have already finished detailed outlines of their respective areas and are starting to write their papers. It is intended to hold a symposium immediately prior to the Annual Conference to be held in May at Atlantic City for the purpose of resolving differences, exploring interrelationships among the areas, and drawing conclusions. An oral report can be expected at the Conference and publication of the various sections of the complete report subsequently.

Among the other activities of the research organization, that of collection, classification, and reporting information on research projects in the profession is a most important one. An increasing number of educational and other institutions as well as industrial firms are undertaking research directed toward improvement in Industrial Engineering techniques or design methodology. In order to avoid duplication of effort and possible resultant waste, it is essential that the research workers in the field know as soon as possible of accomplishments by others. The Intitute is attempting to fill this need through the activities of the Research Information Subcommittee of the Research and Development Committee. Under the continuing chairmanship of Jay Goldman of Washington University this group has set up procedures to collect abstracts of research reports all over the country, classify these appropriately, and publish the results so that individuals interested or active in such research can learn as soon as possible who has worked on a problem and what was accomplished. There have appeared in the *Journal* a number of reports which listed research abstracts and provided such information. Study of the earlier sections of these reports which included various projects carrying back to the war period of the late 1940's quickly shows that a good deal of unproductive and wasteful duplication of activity existed which in all likelihood might have been avoided if more information had been available. The increasing amount of Industrial Engineering research makes such a function all the more important.

At the present time the Research Information Subcommittee has two problems with which it is struggling. One of these is the common problem of the design of a suitable information classification system—one which will meet the needs not only of the *Journal* readers and members of the AIIE who read the series of abstracts but one which will also be adaptable to the information retrieval systems which various technical libraries and research facilities are attempting to develop. The services of various specialists have been sought in the solution of this problem.

The second problem of concern to the men who are trying to provide this very essential service to the professional is the failure of many individuals and organizations to provide annually the requested abstracts and reporting information. Individual members of the Institute and local chapters can be of great assistance in this activity, by encouraging their own organizations, educational institutions, or area institutions to file the requested abstracts. Study of the list of abstracts in the January-February, 1961 or July-August, 1958 issues of the *Journal* should indicate whether a specific organization has taken the trouble to file the information desired. If not, the January 1961 issue of the *Journal* tells how to do so.

Another current activity of a different subcommittee is the preparation of a bibliography of published volumes which has been requested by the Vice President, Professional Services and Planning, Morley Mathewson. This activity is under the direction of Martin Sampson of Cornell University.

In research as well as other activities it is essential from time to time to attempt to look into the future in order to direct more intelligently the affairs of the Institute. David B. Herts is making such a study and is expected to be in a position to make a report in Atlantic City at the time of the next annual conference. It is expected that from this report there will result some guidance in the shaping of the longer range development of the Institute with regard to the research activity.

The research organization has ever since the initial planning for the Atlanta, Georgia Conference assisted in the development of a section of the annual technical program of the Institute by two forms of support. One of these has been the provision of a series of speakers on topics associated with research and development in Industrial Engineering. Although these series have, on

[1] Motto of the Societé des Jeunes Patrons, the "Young Presidents' Organisation" of France.

occasion, been billed in the program as "long-hair" and have usually been held in smaller meeting rooms, their reception has been favorable and to many individuals they have provided most of the substance of the conference. This activity will continue for the Atlantic City Conference in May 1962, and it is expected that some challenging and interesting sessions will be included in the program. In addition to technical sessions during which invited speakers present papers on specified topics, it is the responsibility of a truly professional organization to provide an opportunity for its membership to report upon their research and results and a forum where professionals can meet and debate or describe newly unfolding developments. For the last three annual conventions such opportunities have been provided by setting up, as a part of the conference, sessions at which contributed papers may be presented and discussed. A considerable number of the papers thus presented have been published in the *Journal of Industrial Engineering* and received broader circulation than the invited papers on the conference program as a result. Research, about which the membership might otherwise remain in ignorance for some time, has thus been described and its results presented. It is planned to continue this practice during the Atlantic City conference, and any member who wishes to present a paper at one of the contributed paper sessions should so inform the Director of Research and Development, Andrew Schultz, Jr., at Upson Hall, Cornell University, Ithaca, New York. An announcement of these sessions will appear in the *Journal* and members who are aware of work or results which they believe would be of interest to the membership of the Institute can perform a service by calling the opportunity to report on such accomplishments to the attention of their originators. Some chapters have, in the past, had contributed papers sessions as a part of their chapter activities, and papers of high quality resulting from such activities furnish another possible source of contributed papers.

Research is a time consuming process which in this modern age demands the best intellectual capacity. It is not the sort of activity that is carried out by committees or in odd hours off the job. As a result, it seems unlikely that the AIIE will be in a position to do research itself until a considerable increase in income is available to support full-time activity or sponsor specific projects in appropriate institutions. On the other hand, the Institute is in a position to influence the course of research in the field by the exercise of intellectual and informational leadership. It can call upon various individuals of outstanding competence to collectively define areas of need, appraise results, and publicize or criticize research activities. Most research personnel are rewarded in part by the acclaim of their peers and a professional organization is in a position to provide this. In the initial years of the AIIE's existence, the major objectives of the research activity have been the creation of an organization capable of providing the desired informational and guidance activities. As the Institute matures and more funds become available and its reputation develops to the extent that its influence becomes greater, a new look at the research activity is required. If Industrial Engineering is to assume its proper place in the space age, it must not merely acknowledge the existence of the many new analytical techniques and design methods but assume leadership in the application and further development of them while continuing to demand and support the additional basic developments which are needed. It must also assume leadership in pointing out such needs. All of this requires a greater familiarity and understanding of the methods and substance of research in the field than has existed in the past. How best to achieve this orientation of the Institute remains one of the major challenges facing the AIIE.

AWARDS

DWIGHT D. GARDNER SCHOLARSHIP

WINSTON C. LISTER

Winston C. Lister, a Purdue University senior, has been awarded the 1961-62 Dwight D. Gardner Scholarship, it was announced recently by J. L. Southern, president of the Gardner fund. The $750 scholarship is granted yearly to promising Industrial Engineering students.

Mr. Lister has had a 5.66 average out of a posible 6.0 while at Purdue, is a student member and corresponding secretary of the Purdue student Chapter of the American Institute of Industrial Engineers, a member of engineering honorary Alpha Pi Mu, and school chairman of the Purdue Chapter of Tau Beta Pi, top Industrial Engineering fraternity.

Lister, a native of Preble, Indiana, graduated from Adams Central High in Monroe (Indiana) and was second in his graduating class. His father is postmaster in Preble, Indiana.

The scholarship was named in honor of Dwight D. Gardner, the Institute's first national president. Until his untimely death in 1957, Gardner had been vice president of Commercial Motor Freight, Inc.—Ohio's largest intrastate motor freight company, and one of the top interstate carriers in the nation.

The scholarship fund is administered by five trustees: J. L. Southern, president of the fund, and Industrial Engineer for Commercial Motor Freight, Inc.; Floyd J. Titler, secretary, of Columbus; Howard P. Emerson, head of Industrial Engineering Department at University of Tennessee in Knoxville; Everett Laitala, Industrial Engineering Department head, Clemson College, Clemson, South Carolina; and the noted industrialist W. F. Rockwell, Jr., president of Rockwell Manufacturing Company with headquarters in Pittsburgh, Pennsylvania.

SCHOLARSHIP AWARDED

One of the highlights of the year for Columbus Chapter of the American Institute of Industrial Engineers was their annual scholarship award. The award was given this year to Donald J. Gantser, of Columbus, Ohio, who is an Industrial Engineering student at the Ohio State University. Shown left to right are: Robert M. Wygant, President of the Oklahoma State University Student Chapter; Don Worstell, President of the Columbus Chapter; Donald J. Gantzer, scholarship recipient; and James Shields, Chairman of the Scholarships Committee.

RECOMMENDED CHANGES OF THE MEMBERSHIP QUALIFICATIONS PROVISIONS OF THE CONSTITUTION OF THE AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS, INC.

Readers should refer to the President's Article on page 431 for further explanation.

The Institute is constantly endeavoring to strengthen the qualifications necessary for membership in the AIIE and, at the same time is also concerned that all who are qualified, or are expected to be qualified, shall have the opportunity to become members of the Institute. In order to achieve these objectives the Institute Membership Board of Review has recommended that the following changes and additions to the membership qualifications and classifications be adopted and approved by the Institute membership. Therefore the following amendments to the Constitution are submitted to the membership for approval.

Article IV—MEMBERSHIP, Sections 1 through 3, shall be amended to read as follows (proposed changes are italicized):

Section 1. Add the word *Senior* to Member, so the sentence shall be amended to read "Only *Senior* Members, Fellows and Honorary Members (CG) shall be entitled to hold National offices."

Modify the sentence which now reads: "In addition, there shall be Student Members, Affiliates and Honorary Members," to read

"*The noncorporate membership* shall consist of *Juniors*, Affiliates and Honorary Members. In addition, there shall be Student Members."

Section 2. Definitions of the corporate grades are as follows:

A. An Associate Member shall be:

1. A graduate of an Industrial Engineering curriculum accredited by the Engineers' Council for Professional Development (ECPD), or an engineering curriculum with an option in Industrial Engineering, both accredited by ECPD or, an engineering curriculum accredited by ECPD with a minor in Industrial Engineering, or

2. A graduate of an engineering curriculum accredited by ECPD without Industrial Engineering option or minor, or, a graduate of an Industrial Engineering curriculum not accredited by ECPD, (in either case) with one year of experience in Industrial Engineering in three or more categories as defined in paragraph II of the Classification Manual, or

3. A graduate of an engineering curriculum not accredited by ECPD with two years of Industrial Engineering experience in three or more categories as defined in paragraph II of the Classification Manual, or

4. A college graduate with four years of diversified Industrial Engineering experience in at least four categories as defined in paragraph II of the Classification Manual, or

5. A person with eight years of diversified Industrial Engineering experience in five or more categories as defined in paragraph II of the Classification Manual.

B. *A Senior Member* shall be:

1. A Registered Professional Industrial Engineer who holds, or has held since securing his registration, a responsible position in the Industrial Engineering profession for at least one year, or

2. A Registered Professional Engineer, who holds, or has held since securing his registration, a responsible position in the Industrial Engineering profession for at least two years, or

3. A person, who, in addition to fulfilling the requirements for Associate Membership, has had five years diversified Industrial Engineering experience as defined in paragraph II of the Classification Manual, and has held responsible positions in the profession, or

4. An Associate Member who has had five years of diversified Industrial Engineering experience in responsible positions in the profession.

C. *A Fellow* shall be:

(This section to be modified by substituting the term "Senior Member" for "Member.")

D. *An Honorary Member* shall be:

(This section to be modified by substituting the term "Senior Member" for "Member.")

Section 3. Definitions of the noncorporate grades of membership are as follows: (A new Item A, for the Junior classification, to be inserted)

A. *A Junior* shall be:

1. A graduate of an engineering curriculum accredited by ECPD (no Industrial Engineering option or minor) actively engaged in the field of Industrial Engineering for less than one year, or

2. A graduate of an Industrial Engineering or other engineering curriculum, not accredited by ECPD, actively engaged in the field of Industrial Engineering, but not meeting qualification for Associate Member, or

3. A college graduate actively engaged in the field of Industrial Engineering not meeting the qualifications for Associate Member, but with a minimum of two years of Industrial Engineering experience in two or more categories as defined in paragraph II of the Classification Manual, or

4. A noncollege graduate, with some or no college training, actively engaged in the field of Industrial Engineering not meeting the qualifications for Associate Member, but with a minimum of four years of Industrial Engineering experience in three or more categories as defined in paragraph II of the Classification Manual.

B. Affiliates (no change)

C. Honorary Members (no change)

Section 4. (New section, replacing old Section 3-A. No change in wording). Current Sections 4 and 5 are to be renumbered to read Sections *5 and 6*.

In accordance with the above amendments, the balance of the Constitution and Bylaws shall be amended where necessary as follows: Wherever the term "Member" appears the term "Senior Member" shall be substituted.

PERSONALITIES

ROSS HAMMOND

ROSS HAMMOND

Ross Hammond of Lubbock, Texas, has been appointed director of the Rome office of Georgia Tech's Engineering Experiment Station's Industrial Development Branch.

He will assume responsibility for the program of research and technical assistance which IDB is providing the Coosa Valley Area Planning and Development Commission.

Hammond comes to Tech after eight years as Area Development Engineer with Texas Electric Service Company where he was assistant director of a seventeen-man staff. He subsequently served as director of the Industrial Development Department of the Lubbock Chamber of Commerce for a year.

Research reports by Hammond cover a wide range of technical subjects from "Potential Uses for the Brines and Brackish Waters of West Texas" to market analyses for industrial prospects to long-range employment forecasts for the Texas Electric Service Company itself.

During his tenure with Texas Electric, Hammond served as company liaison man and worked closely with Booz-Allen and Hamilton, EBASCO Services, and other management and engineering consultants. His experience covers the entire range of activities which will be involved in the Coosa Valley industrial development program.

Hammond's employment will bring to three the number of professional staff members assigned to the Rome office. A fourth professional is expected to be added within 30 to 60 days.

Work of the field office staff will continue to be coordinated with the activities of the main office in Atlanta by Dr. George Whitlatch who has been directing field work since the Rome office opened in May. Special capabilities of the more than 30 professional persons now employed by Industrial Development Branch will be utilized as needed to supplement the work of the field office staff.

In addition to a bachelor's degree in electrical engineering, Hammond holds a master's degree in Industrial Engineering. He is a member of the American Institute of Industrial Engineers, the Operations Research Society of America, American Industrial Development Council and Southern Industrial Development Council.

WILLIAM J. VALLETTE

WILLIAM J. VALLETTE

William J. Vallette has been named Manager, Industrial Engineering of Itek Electro-Products Company, a division of Itek Corporation, according to Samuel P. Card, President of the Cambridge, Massachusetts, electronics firm. Mr. Vallette succeeds F. T. Koen who was recently promoted to the post of Director of Manufacturing.

Mr. Vallette joined Special Equipments Division of Itek Laboratories, another division of Itek Corporation, in May of 1961 after 10 years at CBS Electronics as Director of Industrial Engineering. Previous experience includes a post of Chief Industrial Engineer for Hytron Radio and Electronics Corporation.

He joined his present firm when major elements of the Special Equipment Division were merged with the Itek Electro-Products in July.

Mr. Vallette is a 1943 graduate of Massachusetts Institute of Technology, Executive Vice President and member of the National Board of Trustees of the American Institute of Industrial Engineers, and a past chairman of the New England Industrial Engineering Council. He is a registered profesional engineer and a member of the National Society of Professional Engineers.

INTERNATIONAL ACTIVITIES

Dr. Adam Abruzzi, Professor of Industrial Engineering at Stevens Institute of Technology spent approximately six weeks in Milan, Italy in a consulting-teaching assignment with E.N.I. (the national Italian Oil Company). Dr. Abruzzi worked principally in the fields of operations research, statistical analysis and controls. He conferred with other industrial organizations while in Italy, as well as, spending "off" hours with Professor Wilson J. Bentley of Oklahoma State University (who also was consulting in Italy).

* * *

R. B. Heath has been appointed a Senior Market Analyst at the Head Office of The Consolidated Mining and Smelting Company in Montreal. The announcement was made by J. F. M. Douglas, Manager of Market Research, and Mr. Heath will take up his new post in September.

He was born in Adelaide, South Australia. He graduated in mining engineering there in 1941, and following World War II service with the R.A.A.F., obtained his degree in metallurgical engineering (also at the University of Adelaide). He joined Cominco at Kimberley in 1947. He entered method study work at Trail and from 1956 was Supervisor of the Method Study Department.

Mr. Heath is a Fellow of the South Australian School of Mines, a member of the American Institute of Industrial Engineers and a member of the Australasian Institute of Mining and Metallurgy. His community service has included Rotary and Chamber of Commerce work.

CALENDAR

November 6-10: Program Evaluation and Review Technique Course. Operations Research, Inc., 8605 Cameron Street, Silver Spring, Md.

November 20-24: Program Evaluation and Review Technique Course. Operations Research, Inc., 225 Santa Monica Blvd., Santa Monica, California.

December 4-8: Program Evaluation and Review Technique Course. Operations Research, Inc., 8605 Cameron Street, Silver Spring, Md.

December 2: Chicago Chapter Conference, "How to Advance in Your Profession." Northwestern Technological Institute, Evanston, Illinois. Chairman: G. J. Tabern, A. T. Kearney Company, 135 S. La Salle Street, Chicago 3, Illinois.

December 2, 3, 4, 5: International Visual Communications Congress. Biltmore Hotel, Los Angeles, California.

1962

February 1-3: Tenth Annual Material Handling Short Course, sponsored by the School of Industrial Engineering, Georgia Institute of Technology. Write: Director, Short Courses and Conferences, Georgia Institute of Technology, Atlanta 13, Georgia.

A SAMPLING PLAN

Assume that a firm has an implicit policy of buying roughly a quarter year's supply of items in the C class. This policy reflects the desire to avoid "tying up too much money in stock." Some items may be purchased in larger or smaller quantities which is a result of isolated decisions made at random times. But the point is that no one has ever bothered to examine each item separately. Now the question is, what would happen if a policy were set to purchase all items at a half year's supply or even larger?

It would be expected that price breaks would be realized in some of the items although the number involved is unknown. Another advantage would be some reduction in clerical work associated with ordering which could assume some importance because of the number of items in question.

On the other hand the policy of larger lot buying would mean larger holding costs as well as some risks of obsolescence, the latter perhaps being minor due to the nature of the items which in most cases are not direct to the final product.

The purpose of the sampling plan is to estimate the net savings, or loss, that would occur by instituting the policy of ordering in larger lot sizes, in this case a half year's supply. Assume that a firm has about 1000 items comprising the C group. A sample of 50 of these items is selected at random. A table of random numbers can be used to select items from a stock ledger file, or, if no such file is maintained, to select on the basis of physical location. In any event the process should insure that each item making up the group has an equal likelihood of being selected. It is assumed that items are chosen without replacement and that the size of the population is large enough so that error due to non-replacement is minor.

The results of the sample are shown in Table 1.

Column 1—Code number or name of item.

Column 2—Estimated average annual demand for the item.

Column 3—(Q_1) Quantity ordered under the present policy which averages a quarter year's supply with individual variation.

Column 4—(P_1) Unit price when buying in quantities equal to Q_1.

Column 5—(Q_2) Quantity to be ordered under new policy which is equal to a half year's supply.

Column 6—(P_2) Unit price when buying in quantities equal to Q_2. In some cases this reflects a price break while in others no price break is possible.

Column 7—(AP_1) Total annual purchase cost of the item under present policy.

Column 8—(AP_2) Total annual purchase cost of the item under proposed policy.

Column 9—(Col. 7-Col. 8) Annual savings due to price break.

Column 10—($Q_2P_2/2$) Average annual investment in inventory of the item under the proposed policy.

Column 11—($Q_1P_1/2$) Average annual investment in inventory of the item under the present policy.

Column 12—(Col. 10-Col. 11) Added investment in inventory due to buying in larger quantity.

Column 13—(Col. 12 $\times$ 10%) Added holding cost assuming a rate of 10%.

Column 14—(Col. 9-Col. 13) Net savings or loss for the item.

For item number 1, the table indicates that the present reorder quantity is 12 units. The new policy would suggest a reorder quantity of 100 units (a half year's supply) and this results in a price break of \$.062 per unit or \$12.40 savings for the year. The investment in inventory is based on an average inventory equal to one half the reorder quantity. Item number 2 is presently purchased at a half year's supply and has no effect on the new policy. Item number 3 is currently being purchased in a quarter year's supply. No price break is realized by

TABLE 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Item Number	A=Annual Demand-Units	Q_1 Units	P_1 \$	Q_2 Units	P_2 \$	$A\times P_1$ \$	$A\times P_2$ \$	Savings Col. 7-Col. 8 \$	Ave. Inv't. in Inv. $Q_2P_2/2$ \$	Ave. Inv't. in Inv. $Q_1P_1/2$ \$	Added Invest'mt. Col. 10-Col. 11 \$	Added Holding Cost $i\times$(Col. 12) \$	Net Annual Savings Col. 9-Col. 13 X \$	Col. 14 Squared X^2 \$
1	200	12	0.207	100	0.145	41.40	29.00	12.40	7.25	1.24	6.01	0.60	+11.80	139.24
2	2000	1000	0.051	1000	0.051	102.00	102.00	—	—	—	—	—	—	—
3	60000	15000	0.007	30000	0.007	420.00	420.00	—	105.00	52.50	52.50	5.25	− 5.25	27.56
4	24	6	1.700	12	1.500	40.80	36.00	4.80	9.00	5.10	3.90	0.39	+ 4.41	19.45
5	1000	200	0.805	500	0.765	805.00	765.00	40.00	191.25	80.50	110.75	11.07	+28.93	836.94
6	30000	15000	0.011	15000	0.011	330.00	330.00	—	—	—	—	—	—	—
7	160	25	2.200	80	2.000	352.00	320.00	32.00	80.00	27.50	52.50	5.25	+26.75	715.56
8	600	100	0.351	300	0.281	210.00	168.60	41.40	42.00	17.55	24.45	2.46	+38.34	1469.96
9	200	100	0.294	100	0.294	58.80	58.80	—	—	—	—	—	—	—
10	480	120	0.290	240	0.290	139.20	139.20	—	34.80	17.40	17.40	1.74	− 1.74	3.03
11	144	24	0.470	72	0.470	67.68	67.68	—	16.92	5.64	11.28	1.13	− 1.13	1.28
47	400	400	0.200	200	0.235	80.00	94.00	−14.00	23.50	40.00	−16.50	−1.65	−12.35	152.52
48	5000	1000	0.080	2500	0.072	400.00	360.00	40.00	90.00	40.00	50.00	5.00	+35.00	1225.00
49	1200	300	0.202	600	0.202	242.40	242.40	—	60.60	30.30	30.30	3.03	− 3.03	9.18
50	100	20	2.500	50	2.300	250.00	230.00	20.00	57.56	25.00	32.56	3.26	+16.74	280.23
Total													\$142.20	\$4335.16

doubling the reorder quantity and therefore the net result is a loss due to the increased holding costs. Item number 47 is presently purchased at a year's supply and therefore a "negative" price break is incurred by going to the new policy resulting in a loss.

In this example the total net savings for the sample is \$142 20. The estimated average savings per item is \$142.20/50 = \$2.85. Based upon the sample the total expected savings over all of the 1000 items in the C group would be 1000 × \$2.85 = \$2850.

It should again be pointed out that the estimated savings do not reflect certain variables which are affected by the decision, namely:

1. The inventory costs (column 13) do not consider any additional storage costs nor obsolescence. These can be implied in a higher rate of holding than the 10% used in the example.
2. Order preparation costs are ignored and this factor would favor the larger ordering quantity.
3. The investment in inventory fails to consider the matter of buffer or reserve stocks which are considered in setting reorder points. Presumably, a larger order quantity would favor a lower reserve stock investment due to both the lower purchase price and the fact that opportunity for runout of stock is reduced due fewer reorders.

ERROR IN THE ESTIMATE

The average savings (or loss) does not tell the whole story, and it is necessary to reckon with sampling error. This error would be expected to be large due to the considerable variation in the net annual savings of the individual items. This error can be estimated in the following manner.

Let:

x = net savings or loss for an individual item of the sample (column 14).

s_x^2 = estimate of the variance of the population of 1000 items.

$$s_x^2 = \frac{\sum x^2}{N-1} - \frac{(\sum x)^2}{(N)(N-1)} \cong \frac{\sum x^2}{N} - \bar{x}^2$$

$$s_x^2 = \frac{\sum x^2}{50} - (\$2.85)^2 = \frac{\$4355.16}{50} - (2.85)^2 = \$78.98$$

Now let:

$s_{\bar{x}}^2$ = variance of the distribution of averages of samples of size 50.

$$= \frac{s_x^2}{N} = \frac{78.95}{50} = \$1.57$$

Since the distribution of sample means is assumed to be normal the precision of the estimate of savings is stated as follows. There is a 5% risk that the average savings per item is less than \$.78. That is:

$$\bar{x} - 1.65\sqrt{s_{\bar{x}}^2} = \$2.85 - 1.65\sqrt{\$1.57} = \$.78$$

For all items there is a 5% chance that the total savings is less than \$780. The precision of the estimate can be improved by increasing the sample size if the initial small sample yields results which are inconclusive. Since the number of items in the C class is likely to be large the precision of the estimate is dependent on the absolute sample size and not upon its relative size to the total number of items.

The value of the sampling procedure might lie in indicating whether or not it is worth pursuing the idea of buying C items in larger lots. If there appears to be a significant savings due to price breaks then the likely candidates for price breaks in the C groups might be looked at individually at the time of reorder. In this sense the sampling procedure merely directs management's attention to possible savings rather than leading to a general policy that applies to all items.

It should be noted that the previous example assumes some existing implicit policy with respect to purchasing C items. This need not necessarily be the case and therefore one advantage of the sampling procedure would be to establish the nature of the unknown status quo with respect to purchasing C items in comparison with some stated lot size policy as a bench mark.

SUMMARY

A sampling plan is proposed which economically measures the potential savings due to price breaks in class C items in inventory. Class C items constitute the majority of items carried in stock yet contribute a small percentage to the total inventory value. Because of their large number it is usually uneconomical in clerical time and effort to examine each item individually in order to determine an economic purchase lot size. The sampling plan establishes the nature of the existing purchase policy for these items as a group, and then measures the net savings (or loss) resulting from a change in policy. The effect of price breaks as well as holding costs is evaluated.

This is an example of many situations in accounting where the cost associated with a detailed examination of each item of a population does not justify the precision in the results obtained. Examples of situations where exact measurement can unduly tax accounting resources are:

1. Taking a physical inventory on C items in stock. Again, for the majority carried in stock most of the effort expended on physical inventory may result in a small aggregate adjustment to the inventory account.
2. Small customer orders can account for the majority of orders received yet comprise a small percent of the total income. An inordinate amount of accounting effort can be spent in costing and pricing these orders.
3. Auditing of invoices where, again, the file is replete with small billings.
4. The finished goods inventory may contain a large number of slow moving items. Attempts may be made to establish economic manufacturing lot sizes for each item.

When exact information about each item of the population is decreed then a counting job of some considera-

ble magnitude is involved. From such detailed counting the resultant gains in control, savings, or profit, even in the aggregate, can be negated in light of opportunities to be gained from alternative uses of accounting effort. In certain decision making situations the information may be desirable but not mandatory. Thus, if the stoic resolve necessary for a massive assault on the details is lacking, the decision may well be made without the aid of the information.

It is in situations such as these that there is a "payoff" in statistical sampling which can provide the desired information at a reasonable cost and with a precision that is compatible with the objectives and results.

The Use of Learning Curve Theory in Setting Management Goals

by **JAMES M. WHITE**

Associate Professor, Industrial Engineering Department, Stevens Institute of Technology

STATISTICAL control techniques are being used on an increasingly wider scale on industrial management. A characteristic feature of these techniques is that it is impossible to determine in advance the controlled state that will be achieved eventually. Control, in a statistical sense, is achieved when further improvements cannot be made and stable conditions exist, although theoretically there is no limit to the improvements that can be made. When statistical control is achieved, control may or may not be satisfactory from management's point of view, depending upon the criteria used for determining control requirements. Basically, a satisfactory controlled state requires a satisfactory level of performance and control limits that are not excessively wide.

If management is interested in improving the performance of some operational factor, management must first analyze the problem and determine what action needs to be taken. The use of particular techniques rarely, if ever, obviates the necessity of doing this preliminary work. They may be very effective tools but management should always be aware of their limitations. There is a tendency for managements to expect more of these techniques than it was ever intended they would accomplish. To take a specific illustration, let it be supposed that management believes that wastage losses of materials are too high. Even though management believes that statistical control techniques may be helpful in improving this factor, a careful study of the causes of waste and possible ways of eliminating these causes is essential for maximizing results from a waste control program.

It is also highly desirable that management predetermine the rate of improvement expected, that is, management must set goals as an incentive to accomplishment. The two processes of analyzing operations and setting goals are mutually reinforcing. This presentation is concerned with a technique for setting goals in a situation where the expected improvement cannot normally be predicted by objective criteria, such as in the case of using statistical control concepts as discussed above. The suggested technique is to apply learning curve theory and methods which were developed initially by the aircraft industry.

LEARNING CURVE THEORY

Learning curve theory was originally developed from empirical studies in the aircraft industry to predict the relationship between cost and quantity of production. Practice in application has continually improved to the point where it is now widely accepted as the most reliable technique for developing cost estimates. Briefly, the theory is that learning, or improvement, continually takes place in making custom-built, complicated products so that each successive unit costs a little less than its predecessor. The generally accepted form of the learning curve equation is $y = ax^b$ where, using aircraft industry terminology, y is the cost per pound of the xth unit produced ($x = 1, 2, \ldots, n$), a is the cost per pound of the first aircraft made, and b ($b < 0$) is a parameter which is dependent upon the type and complexity of a particular aircraft. In order to apply the equation, the parameters a and b must be estimated (from past experience).

The learning curve equation is such that the logarithms of x and y are in a linear relationship, given by the equation $\log y = \log a + b \log x$. The relationship has the convenient property that every time x doubles, successive values of y are a constant multiple (some fraction between 0 and 1) of the preceding value. This multiple of y, expressed as a percentage, is commonly called the learning factor, or the learning curve "slope." This latter term is misleading since it is mathematically illogical—it is

neither the slope of y nor of $\log y$. In other words, when the "slope" is plotted on log-log paper, it is defined as the unit cost at quantity $2x$ divided by the unit cost at quantity x, expressed as a percentage.

Learning curves are often identified by this percentage. Thus, an 80 percent curve is one where the second unit costs 80 percent as much as the first unit, the fourth unit's cost is 80 percent of the second unit's, etc. The relationship between the "slope" and b is given by the equation: "slope" $= 2^b$. Thus, for a "slope" of 80 percent, $b = -0.322$. For the learning curve equaton, it should be noted that y approaches zero as x becomes very large. These two features, namely, linear logarithmic relationship[1] and zero as the limit of y are sometimes criticized but the equation as given continues in almost universal use.

APPLICATION TO WASTE REDUCTION

Conceptually, it is quite logical to regard the study of waste-causing processes as a learning process in which we are learning how to reduce and control wastage losses. Furthermore, it is commonly believed on intuitive grounds that improvements in operations are often made at a decreasing rate. Admittedly, there is not much evidence to support these beliefs. Even if such evidence were available it would probably be inconclusive, because the making of improvements has often been a rather haphazard process whereas learning curve theory presupposes an intensive and well-thought improvement effort. But the potentialities in the use of learning theory as a tool in the study of the management process seem to offer some interesting applications.

The approach to applying learning curve theory in setting goals for waste reduction is basically the same as its use in the aircraft industry. It is believed that the standard learning curve equation can be used to predict the rate of reduction in wastage losses. This hypothesis must be tested empirically. The parameters to be used must be developed from experience. Initial applications may be somewhat uncertain but skill should improve as experience is accumulated. The problems encountered by the aircraft industry in developing this technique were overcome and today it is a widely-used and very effective tool. The problems in adaptation ought not to prevent its use for other purposes and by other industries.

It is quite likely that the learning curve technique will have to be modified according to the purpose for which it is used. In using it to set goals for improvements in waste control, the number of units of output is not a practical basis for application. Assuming that the rate of output does not fluctuate too widely, we may try time as an equivalent measure to the number of units of output. To illustrate, let it be assumed that wastage losses are initially about 15 percent. Arbitrarily selecting the month as the unit of time and assuming a 90 percent learning factor, then reduction in waste should take place according to the following schedule.

Period	*Wastage Losses at End of Period*
1 month	13.5%
2 months	12.2%
4 months	10.9%
8 months	9.8%
16 months	8.9%
32 months	8.0%
64 months	7.2%

It is obvious that problems in using this technique will arise. A few of these are considered in the following discussion. One question concerns the timing of the program—"at what point did the program start?" It is clear that a preliminary investigation must be made before the decision to institute a program of waste control is made. Furthermore, the program is not likely to get underway until some time after the decision has been made. This suggests that, for the purpose of setting goals, the initiation of the program should not be considered to have started until all preliminary investigations have been completed and the program is in full swing. This may be several months after the decision to undertake the program has been made.

Experience has indicated that after a period of steady improvement, increasing refinements resulting from learning will be made at a decreasing rate. A point will eventually be reached at which the value of the improvements obtained will not be worth as much as the effort expended in effecting improvements. As yet there has been no substantial development to indicate when this point is reached in the program. Nevertheless, the application of the learning curve technique can achieve worthwhile results in management planning.

CONCLUSIONS

There has been a singular lack of progress in extending the use of learning curve theory outside of the aircraft industry. Specific examples of such applications, together with an evaluation of their usefulness, are extremely hard to find. Managements are slow to adopt new techniques, particularly in the form of mathematical models. It is a truism to say that at present either no targets are set for improvements or such targets are only unsubstantiated guesses. It is questionable whether a department executive who is told, arbitrarily, that he must reduce his budget by 25 percent will achieve this reduction or, if he is successful, whether the net result will be to the company's benefit.

It does seem reasonable to assume that, lacking realis-

[1] The linear relationship is usually questioned from the point of view of goodness of fit. Occasionally someone advocates rounding off the first part of the line and/or the last part of the line, or changing the parameters for different segments of the line. That these modifications improve the model is problematical.

tic targets and with insufficient analysis as to how those targets are to be achieved, performance will fall short of that which is possible of attainment. Thus, in the case of the reduction in wastage losses discussed, a more haphazard process of reducing wastage losses may result in a lower learning factor, say 95 percent. The effect of this is that wastage losses are down to 10.1 percent at the end of 32 months as compared to 8.0 percent associated with a 90 percent learning factor. If further work ceased at this point, losses (and costs) would be 25 percent higher with a 95 percent factor than would be the case if the learning factor were 90 percent. Furthermore, with such a slow rate of progress, there would be the possible danger of an early loss of interest in the program which would curtail the improvement still more.

Other than the example discussed in this article, there are many similar situations where learning curve theory could be used to predict the expected rate of improvement. Possible cases could be: reduction in scrap and rejects, increase in the yield of a process, decrease in accident rates, decrease in unutilized capacity due to poor planning and control in the use of resources, reduction in the length of the manufacturing cycle, improvement in accuracy of cost estimates, reduction in clerical errors, etc. In short, the method would generally be applicable in a situation where a complex factor of operations is measurable and is initially in what would be considered an uncontrolled state. Although the examples cited are from the field of production, it is probable that examples in other fields could also be found.

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Speed Up the Solution to Linear Programming Problems

by **F. P. FISHER**

Western Regional Office, International Business Machines Corporation

LINEAR programming has become a valuable aid in selecting the most profitable or least costly mode of industrial operation. There have been two major difficulties in applying linear programming techniques:

1. Formulation of the problem.
2. Performing the lengthy arithmetic calculations.

The abundance of literature published on this subject, coupled with experienced personnel, has made possible the formulation of most linear programming problems, and problems involving a hundred or more variables can now be solved in a matter of hours through the use of high speed computational equipment.

It is becoming more apparent however, that there is a third and equally important consideration: the optimization of the linear programming and computational techniques. A knowledge of linear programming alone is not enough. It is also necessary to be familiar with the exact nature of the particular problem and "short-cut" linear programming methods in order to obtain the most efficient solution. For example, "condensation," in which variables that will not appear in the final solution are eliminated from the starting matrix, has long been used to speed linear programming solutions.

This article presents a general review of linear programming which will serve as a background to the discussion of "forced inversion," a linear programming algorithm that can solve problems in a minimum of computational time.

Forced inversion is a very simple modification of standard linear programming methods. Aside from the speed of solution, it offers additional advantages over conventional "simplex" methods (1):

1. Negative "right hand sides" may be included, and artificial variables do not have to be used. This action will reduce the size of the problem to be solved.

2. Forced inversion speeds solution by using a simpler transformation scheme and by reducing the number of total transformations. For a large problem, this may improve the loss of significant digits in the answer, due to "round-off" error.

3. There are instances where it is desired to force variables into the final solution with no concern for optimality. This may be a result of production limitations, competitive situations, etc. Conventional linear programming methods cannot do this without using a dummy cost function.

4. "Composite algorithms" (2) are available which allow the starting matrix to have an infeasible basis (negative right hand sides). However, "cycling" can occur as the composite algorithm is attempting to obtain a feasible basis. This is characterized by one or more variables continually going in and out of the basis solution with no improvement in the profit function. Since forced inversion ignores all criteria for feasibility and proceeds directly toward the final solution, no cycling can occur during the use of the forced inversion algorithm. However, it must be pointed out that if the solution is not complete at this point and the solution has to be optimized with other algorithms, cycling can occur.

If the selection of variables to be in the final basic solution is accurate, the maximum number of matrix transformations to reach an optimal solution will be m, the number of constraint equations. Usually the number of transformations will be less than m, with a total solution time only 25-50% of the time utilizing conventional linear programming methods. It must be stressed, however, that the advantages of forced inversion decrease rapidly if the selection of the final basis variables is inaccurate.

LINEAR PROGRAMMING REVIEW

Linear programming is a method for optimizing a linear function $f(x_1 x_2 \cdots x_n)$ when the variables $x_1 x_2 \cdots x_n$ are subject to a set of linear constraints. Stated mathematically, values $x_1, x_2, \cdots x_n$ are required which satisfy:

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n &\leq b_1, \\ a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n &\leq b_2, \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots & \\ a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n &\leq b_m; \end{aligned} \qquad \text{Eq. 1.}$$

where

$$x_i \geq 0 \qquad \text{for all } i, \qquad \text{Eq. 2.}$$

and such to make a maximum

$$F = C_1X_1 + C_2X_2 + \cdots + C_nX_n. \qquad \text{Eq. 3.}$$

The numbers a_{ij}, b_i, C_j are given constants, and m is the number of constraint equations and n is the total number of variables.

Before the method of solution is discussed, certain definitions are in order:

Feasible Solution = A solution that satisfies Eq. 1. and Eq. 2. but not necessarily Eq. 3.

Maximal Solution = A solution that satisfies Eq. 1., Eq. 2. and Eq. 3.

Basic Feasible Solution = A feasible solution with not more than m nonzero and positive values of X_i.

Basic Maximal Solution = A maximal solution with not more than m nonzero and positive values of X_i.

The solution to any linear programming problem can only have m values of X_i. If the solution has more than m positive values X_i, it is always possible to find a solution with a fewer positive values X_i which is better or as good.

The "simplex method" for solving linear programming problems is to:

1. Construct a basic feasible solution.
2. If an optimum has not been reached, replace a basis variable with a nonbasis variable and obtain another basic feasible solution.
3. Continue until an optimum is reached.

The simplex method requires a basic feasible solution before the solution can begin. (Other methods, as the composite of forced inversion, allow computation to begin with an infeasible basis.) To construct an initial basic feasible solution, we must convert inequalities to standard equalities, and construct a "unit basis."

CONVERSION OF INEQUALITIES TO STANDARD EQUALITIES

Multiply through by -1 where necessary to make all $b_i \geq 0$ Eq. 4.

Where $b_i = 0$, multiply through by -1 where necessary to convert inequalities of the type $\sum a_{ij}X_j \geq 0$ into $\sum a_{ij} \leq 0$ Eq. 5.

Replace inequalities of the type

$$a_{i1}x_1 + \cdots + a_{in}x_n \leq b_i \quad \text{by the equalities}$$

$$a_{i1}x_1 + \cdots + a_{in}x_n + s_i = b_i \qquad \text{Eq. 6.}$$

Replace inequalities of the type

$$a_{i1}x_1 + \cdots + a_{in}x_n \geq b_i \quad \text{by the equalities}$$

$$a_{i1}x_1 + \cdots + a_{in}x_n - s_i = b_i \qquad \text{Eq. 7.}$$

The additional variables s_i take up the "slack" by which the inequalities depart from the equalities, and are called "slack variables." They may enter into the final solution, but make no contribution to the profit function and therefore have cost coefficient, $c_j = 0$.

CONSTRUCTION OF A UNIT BASIS

To facilitate the solution of the linear programming problem a "unit basis" is constructed. Each equation (row) of the matrix must have one variable, with a coefficient of unity, that does not appear in any of the other constraint equations. At any stage of the solution, the basis variables are equal to the corresponding b_i's. Variables not in the basis have a value of zero.

There are three ways the unit basis may be formed:

1. a_{ij}'s in a unit column. Eq. 8.
2. Each slack variable supplied by Eq. 6. but not by Eq. 7. Eq. 9.
3. Artificial variables. Eq. 10.

Artificial variables have no place in the final solution. To insure their elimination from the basis, they are assigned large negative cost coefficients. Therefore, the functional cannot reach its maximum while any feasible solution contains an artificial variable. The use of artificial variables to obtain a starting basis will be illustrated in the first example problem.

With the introduction of standard equalities and the unit basis requirements, the linear programming problem may now be stated.

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n &= b_1 \\ a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_2 &= b_2 \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n &= b_m \end{aligned} \qquad \text{Eq. 11.}$$

where matrix of a_{ij} is equal to

$$\begin{matrix} 1 & 0 & 0 \cdots 0 \\ 0 & 1 & 0 \cdots 0 \\ \cdot & \cdot & \cdot \quad \cdot \\ 0 & 0 & 0 \cdots 1 \end{matrix} \qquad \text{For } j \leq m$$

$$\text{maximize } F = C_1X_1 + C_2X_2 + \cdots C_mX_m \qquad \text{Eq. 12.}$$

$$\text{for} \rightarrow b_i \geq 0, \quad X_i \geq 0 \qquad \text{Eq. 13.}$$

The basic feasible solution is

$$\begin{aligned} x_i &= b_i \quad (i \leq m) \\ x_i &= 0 \quad (i > m) \end{aligned} \qquad \text{Eq. 14.}$$

INTRODUCTION OF A NONBASIS VARIABLE INTO THE BASIS

The simplex method can best be described with the use of a simple example. Consider the maximization of $F = X_1 + X_2$ subject to constraints:

$$X_1 + 2X_2 \leq 6 \qquad \text{Eq. 15.}$$

$$X_1 - X_2 > 3 \qquad \text{Eq. 16.}$$

converting to standard equalities.

$$X_1 + 2X_2 + S_1 = 6$$

$$X_1 - X_2 - S_2 = 3$$

From Eq. 9., the slack variable, S_1, supplies the unit basis requirement for the first equation. However, it is necessary to add an artificial variable to the second equation. The constraints then become:

$$X_1 + 2X_2 + S_1 = 6$$

$$X_1 - X_2 - S_2 + A_2 = 3$$

Table 1 is the systematic arrangement of this problem into matrix form.

The C_i's and C_J's are the original cost coefficients for the basis and nonbasis variables respectively. Notice a large negative cost (-10) has been assigned to the arti-

TABLE 1

C_i ↓	C_j →	1 X_1	1 X_2	0 S_1	0 S_2	−10 A_2	0 b_i	
0	S_1	1	2	1	0	0	6	
−10	A_2	1 (a_{rk})	−1	0	−1	1	3	← a_{rj}'s
	$Z_j - C_j$	−11 ↑ a_{ik}'s	9	0	10	0	−30	

ficial variable A_2 to insure its removal from the final basis. The elements in the last row of the matrix, $Z_j - C_j$, are referred to as "shadow prices" and are used to determine which variable, if brought into the basis, would tend to increase the profit function most significantly. For the jth column of the matrix they are calculated from the relationship:

$$Z_j - C_j = \sum_{i=1}^{m} C_i a_{ij} - C_j$$

Notice that the last entry in this row is the current value of the profit function, since C_j is zero and $Z_j - C_j$ reduces to

$$\sum_{i=1}^{m} C_i a_{ij} = \sum_{i=1}^{m} C_i b_i = \sum_{i=1}^{m} C_i X_i$$

It can be shown that the profit function will be a maximum when there are no more negative $Z_j - C_j$. The variable with the most negative $Z_j - C_j$ is brought into the basis during each transformation. Referring to Table 1, this variable is X_1.

The variable leaving the basis, X_i, corresponds to the minimum positive ratio b_i/a_{ik} for $b_i > 0$ where I is the variable entering the basis. For the example problem, the ratios are 6/1 and 3/1 for S_1 and A_2, respectively. Therefore, A_2 will be removed from the basis.

To bring a variable into the basis, it must be transformed into a unit column with the coefficient of 1 in the row corresponding to the variable leaving the basis. This is accomplished by simple matrix elimination. Linear programming computer codes utilize the following relationship to perform the transformation.

$$a_{ij} = a_{ij} - \frac{a_{rj}}{a_{rk}} a_{ik}$$

where

k = variable coming into the basis (pivot column).
r = variable leaving the basis (pivot row).

Stated in words:

1. Divide the pivot row (a_{rj}'s) by the pivot element (a_{rk}).
2. Multiply the pivot row by the a_{ik} of the row being transformed. Subtract the pivot row from this row.
3. Continue for all rows of the matrix.

Tables 2, 3, and 4 illustrate the results of the first, second and third transformations, respectively.

TABLE 2

C_i ↓	C_j →	1 X_1	1 X_2	0 S_1	0 S_2	−10 A_2	0 b_i	
0	S_1	0	3 (a_{rk})	1	1	−1	3	← a_{rj}'s
1	X_1	1	−1	0	−1	1	3	
	$Z_j - C_j$	0	−2 ↑ a_{ik}'s	0	−1	11	3	

TABLE 3

C_i ↓	C_j →	1 X_1	1 X_2	0 S_1	0 S_2	−10 A_2	0 b_i	
1	X_2	0	1	$\frac{1}{3}$	$\frac{1}{3}$ (a_{rk})	$-\frac{1}{3}$	1	← a_{rj}'s
1	X_1	1	0	$\frac{1}{3}$	$-\frac{2}{3}$	$\frac{2}{3}$	4	
	$Z_j - C_j$	0	0	$\frac{2}{3}$	$-\frac{1}{3}$ ↑ a_{ik}'s	$10\frac{1}{3}$	5	

TABLE 4

C_i ↓	C_j →	1 X_1	1 X_2	0 S_1	0 S_2	−10 A_2	0 b_i
0	S_2	0	3	1	1	−1	3
1	X_1	1	2	1	0	0	6
	$Z_j - C_j$	0	1	1	0	10	6

The optimum has been reached when there are no more negative $Z_j - C_j$. The final solution, Table 4, is:

$$P = 6$$
$$S_2 = 3$$
$$X_1 = 6$$
$$X_2, S_1, A_2 = 0$$

THE COMPOSITE ALGORITHM

Since most linear programming problems are solved by digital computers with a fixed memory size, artificial variables decrease the size of the allowable matrix. Also, the additional variables increase the computing time. A "composite" algorithm will eliminate this problem by allowing the constraints to be specified with negative right hand sides. If the second constraint (Eq. 16.) is multiplied through by −1, the equation becomes:

$$-X_1 + X_2 + S_2 = -3$$

The slack variable, S_2, now supplies the unit basis requirement for this equation. The new matrix is illustrated in Table 5.

TABLE 5

C_i ↓	C_j →	1 X_1	1 X_2	0 S_1	0 S_2	0 b_i
0	S_1	1	2	1	0	6
0	S_2	−1	1	0	1	−3
	$Z_j - C_j$	−1	−1	0	0	0

In case of a tie for the pivot column (identical $Z_j - C_j$'s), the simplex procedure usually selects the first of

the subject columns. However, in a composite algorithm, it is necessary to have a different criterion for selecting the variable to enter the basis since both optimality *and* feasibility must be considered. All nonbasic vectors (columns) of the matrix become potential pivot columns because consideration of the shadow price alone is not enough to insure that the transformation will move toward feasibility. One technique is to calculate a "pseudo shadow price" as follows:

pseudo shadow price

$= (Z_j - C_j)$(Scale Factor)

$+ a_{ij}$'s in this column for all rows with negative b_i's.

A small scale factor tends to select the column with the largest number of negative a_{ij}'s. These negative numbers are forced toward zero when unit column is formed, which will add positive quantities to the b_i's. As soon as all b_i's become positive, a "straight simplex" method is utilized to complete the optimization.

Assuming a scale factor of .01, the pseudo shadow price for the example problem becomes:

$j = 1, \quad psp = (-1)(.01) + -1 = -1.01$

$j = 2, \quad psp = (-1)(.01) + 1 = 0.99$

Therefore X_1 will enter the basis. The variable to leave the basis is selected in an identical manner to the "straight simplex" algorithm

$i = 1, \quad bi/aik = 6/1 = 6$

$i = 2, \quad bi/aik = -3/-1 = 3$

Variable S_1 will leave the basis. Even though S_2 has the minimum positive ratio it could not be selected as the pivot row because of the negative b_i.

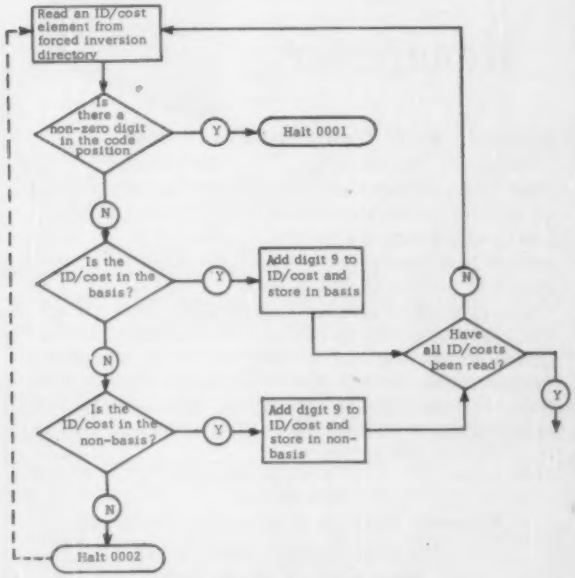

FIGURE 1. Identification of Final Basis Variables.

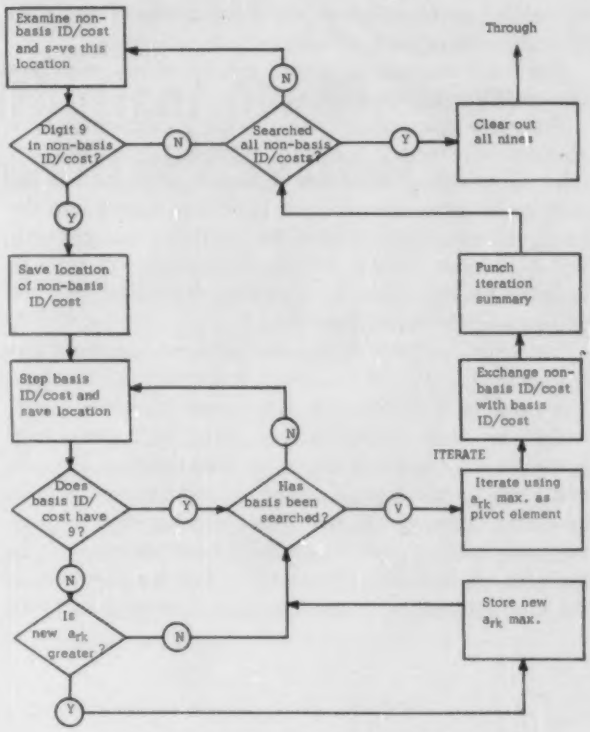

FIGURE 2. Forced Inversion.

After one transformation, Table 6, the problem is optimized, as contrasted with three transformations for the straight simplex method.

TABLE 6

C_i	$C_j \rightarrow$	1 X_1	1 X_2	0 S_1	0 S_2	0 b_i
1	X_1	1	2	1	0	6
0	S_2	0	3	1	1	3
	$Z_j - C_j$	0	1	1	0	6

FORCED INVERSION

Many times the analyst has a good idea as to the form of the final solution to his problem. This is especially true when only a minor change is to be made in a problem that was previously solved. In cases of this type "forced inversion" may be used to great advantage. The efficiency of this technique is dependent on how good a guess can be made as to the form of the final solution. The ability to predetermine which variables will be in the final solution may appear difficult; however, experience has indicated it is often possible to guess up to 90% of the final solution.

Once conventional linear programming techniques are mastered, the forced inversion algorithm becomes only a simple modification. In forced inversion the final basis variables are preselected and identified in the matrix.

Successive pivot columns are those nonbasis variables that are to be in the final basis.

For each successive pivot, column pivot rows are chosen in the following manner:

Select the row corresponding to the maximum positive element (a_{ik}) within the pivot column. Do not consider rows representing variables that are to remain in the final basis. After all variables have been forced into the basis, the solution is checked for feasibility and optimality. A variable number of transformations will have to be made by the composite algorithm depending upon the accuracy of the initial guess.

Referring to Table 5, assume previous experience has indicated that X_1 and S_2 should be forced into the basis. For instance a problem of like nature involving essentially the same variables may have been previously solved and X_1 and S_2 were in the final solution. Since S_2 is already in the basis, only one transformation will be necessary. Variable X_1 will come into the basis replacing variable S_1, the only remaining basis variable not in the "Forced Inversion Directory." After transformation, the final solution is identical to that illustrated in Table 6.

This simple example was chosen for illustration purposes only and did not illustrate the advantages of forced inversion which are in review. They are:

1. Faster matrix transformations. The method of selecting the pivot element is simpler than either the simplex or composite algorithms.
2. "Bypassing" of the cycling problems encountered in the use of a composite algorithm.
3. A smaller number of transformations. Experience has indicated that the time to solve a problem using forced inversion *can* be 25–50% of other methods.

Forced inversion is one of the linear programming options available for the IBM 650. The "flow" for forced inversion is illustrated in Figure 1 and Figure 2. A reduction in the number of partitioned passes through the use of forced inversion will greatly reduce the time necessary to obtain an optimal solution.

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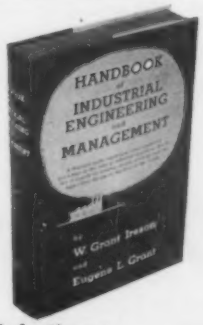

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Simulation of a Hypothetical Multi-Item Production and Inventory System[1]

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THIS study is concerned with the use of computer techniques to simulate the behavior of an idealized multi-item production and inventory control system—the case of a producer manufacturing standardized items for stock. As in the classical case of single-item inventory control, we shall be concerned with the determination of optimal reorder points and order quantities. However, since this is supposedly an integrated production and inventory system, we shall also be concerned with the interaction that exists between the ordering decisions and the corresponding delivery lags.

What gives rise to such interaction? Suppose that in order to economize upon inventory costs, the control rules call for only small production runs of each item. The effects will not then be confined to the direct increase in setup costs. For a shop of given capacity, short production runs will result in more frequent setups, and hence an increased rate of facility utilization, increased congestion and waiting lines.

However, with long production runs, there is an increase in mean processing time per order, and hence the danger that unless the queue length happens to be zero, the increase in total delay time may conceivably wipe out any benefits derived from the reduction in setup time costs. In the absence of good analytical methods, we have employed computer simulation for the study of this problem.

Given our basic simplifying assumptions—a single bottleneck facility, Poisson customer demands for each stock item, identical customer demand rates and identical manufacturing times for all items—there is one special case to which analytical methods are applicable. With a reorder quantity of unity and with a reorder point of zero, this inventory control problem becomes isomorphic with the Palm-Feller machine servicing problem (2). Furthermore, with a reorder point of zero and with the reorder quantity a positive integer q, the inventory control problem becomes isomorphic to a machine servicing problem in which the time to breakdown is described by a gamma distribution with q phases. Our computer simulation for this case suggests that a gamma distribution for individual reorder times (or machine breakdown intervals) does not result in a very different distribution of queue lengths than is implied by a negative exponential distribution with an identical mean.

THE INVENTORY PRODUCTION SYSTEM

It will be assumed that the system carries stock on m different items, and that the demand for each of these items is randomly distributed, and independent of the demand for the other items. Customer demand continuously depletes the available stock of each item, and at the time that the inventory reaches a specified reorder level, an order is placed for the shop to produce a *fixed* order quantity.

In general a manufacturing plant will contain a large number of production facilities—each a potential bottleneck point in the operation. For purposes of this model, we shall ignore the existence of multiple bottlenecks, and concentrate upon the case where a single facility governs the capabilities of the entire plant.

Two of the parameters of this stochastic process lie beyond the control of the production and inventory manager: the processing capacity and the demand rates for individual items. But the characteristics that lie within his control are the reorder levels, the order quantities, and the job priority rules. The performance of alternative stockage policies and priority rules is to be judged primarily in terms of three criteria:

1. Average inventory levels.
2. Number of lost sales.
3. Average facility utilization.

To the extent that monetary costs can be associated with each of these three indices, the overall performance of alternative systems may be compared directly in terms of dollar costs.

[1] Based upon a presentation to the Seventh Annual International Meeting of The Institute of Management Sciences in New York City, October, 1960.

[2] Presently with Stanford University.

DEFINITIONS

Parameters

a_i = mean setup time required to produce the ith item.

b_i = mean unit process time required to produce the ith item.

d_i = mean arrival rate of customer demands for ith item.

m = number of products in the system.

Decision Variables

r_i = reorder level of the ith item.

q_i = order quantity of the ith item.

Additional Quantities

$t_i = a_i + b_i q_i$ = mean servicing time required to process an order quantity of the ith item.

d_i/q_i = approximate mean arrival rate of stock replenishment orders for the ith item at production facility; (neglects demands that result in lost sales).

THE SIMULATION PROGRAM

Two major goals were associated with this study: first to simulate a production inventory system with interactions between the stockage policy and the replenishment delay time; and second, to check the results for certain cases against those predicted by the Palm-Feller model.

The simulation consisted of Monte Carlo sampling from a Poisson process to generate customer demands for individual items; the use of logical computer commands to simulate the control system; and the performance of detailed record-keeping tasks so as to produce the required information on the system behavior. Figure 1 presents the flow chart of the simulation program.

The flow chart indicates that two basic record-keeping functions are simultaneously performed in the computer program. Firstly, the inventory activity of the individual items can be visualized in terms of a "two-bin" process. On each cycle the arrival of a replenishment order sets the inventory at some maximum level. This inventory is then depleted one unit at a time by incoming customer demands. Eventually the inventory level drops to the reorder point; the "first bin" is emptied; and thereupon a reorder quantity is issued for new supplies. After an interval known as the "replenishment time" the order quantity is delivered into the inventory raising it to its maximum level and the cycle starts over again. During the replenishment interval, it is possible that inventories will be depleted to zero. We ignore the possibility of backlogs in demand under these conditions. If no inventory is on hand, incoming demands are not filled, and these are regarded as "lost sales."

The reorder quantity is always adjusted here so as to be greater than the reorder point. Without such a constraint—and with a constant order size—if the inventory

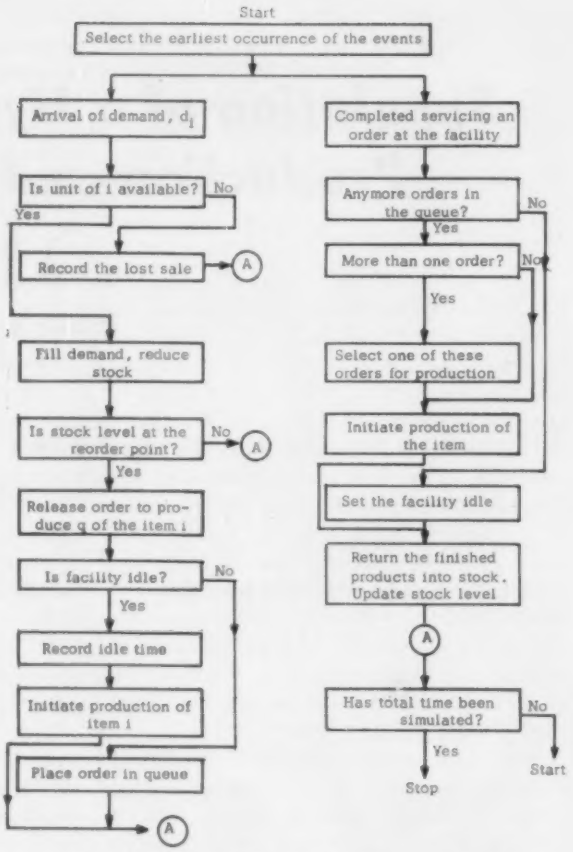

FIGURE 1. General Flow Chart of System Activity.

ever dropped to zero, it could never again exceed the order point. Here, the "bin" sizes are constraints so that the first is always larger than the second bin. This constraint turns out to be a significant one.

The activity at the production facility is controlled by a priority rule that governs the replenishment assignments. For instance if the facility is idle and an order quantity arrives to be processed, the processing will be started immediately. However, if the facility is busy, the arriving job is delayed, and a waiting line is formed. We have experimented here with only one of many possible job priority rules: first-come, first-served. As soon as the facility completes processing a job, the corresponding quantity of goods is immediately credited to the current inventory of the stock item.

The Poisson assumption specifies the behavior of demand arrivals by postulating that the time between two successive arrivals is exponentially distributed. With a mean arrival rate of d_i:

$\theta_i(x)dx = d_i e^{-d_i x} dx$ = probability that exactly x units of time elapse between two successive customer demands for the ith item.

Hence, the mean customer demand per item (mean

arrival rate) is denoted as d_i demands per unit time. (Note the importance of the assumption of independence of demands as between individual stock items, as well as between successive demands for a single item.)

All items are manufactured one-at-a-time on the single bottleneck facility. Mean processing or service times for individual job order quantities of size q are determined by a linear equation, with a_i being the mean setup time for

$$t_i = a_i + b_i q_i. \qquad \text{Eq. 1.}$$

The value t_i is specified as the mean of a negative exponential distribution of servicing time.

In order to simplify the analysis, we have found it convenient to assume complete symmetry in the parameters for all stock items. This symmetry assumption results in an identical reorder level and order quantity common to all items. The following numerical parameter values have been employed in our studies:

$m = 2, 5, 10$ items in inventory.
$d_i = d = .05, .10$ customer order per unit of time.
$a_i = a = 4$ units of time per setup.
$b_i = b = 1$ unit of processing time per unit of stock item i.
$q_i = q = 1, 2, 3, 5, 10, 15, 25, 30, 40, 50, 60, 80, 100, 120$ (order quantity).
$r_i = r = 0, 2, 4, 6, 8$ (reorder point).
$t_i = t = a + bq = 4 + q =$ mean servicing time for an order quantity of size q.

The data recorded during the stationary phase of each simulation run consisted of the following results:

1. Total customer demand per item.
2. Total customer demand lost per item.
3. Total number of stock replenishment orders (setups).
4. Facility utilization rate.
5. Average inventory per item.
6. Sample distribution of waiting orders.
7. Average number of orders waiting for processing at the facility.
8. Average replenishment time per order quantity.

The total number of time units included in each simulation run was set in such a way as to overcome the arbitrary initial transient conditions, and to insure stochastic stationariness. A number of checks were made in order to check for stationariness. As nearly as could be determined, the transient conditions were overcome after the completion of approximately two reorder cycles on each item.

SIMULATION RESULTS

A. *Test on the effect of varying the replenishment order size on 1. the facility utilization rate, 2. average inventory levels, and 3. the proportion of lost sales.* A series of simulation runs were made which measured the above quantities; (at reorder level, $r = 2$) and the replenishment quantities q were varied in size from 3, 5, 10, 15, 20, 30, 40, 50, 60, 80, 100, 120. Figure 2 presents the relationship between these quantities with variation in replenishment order size.

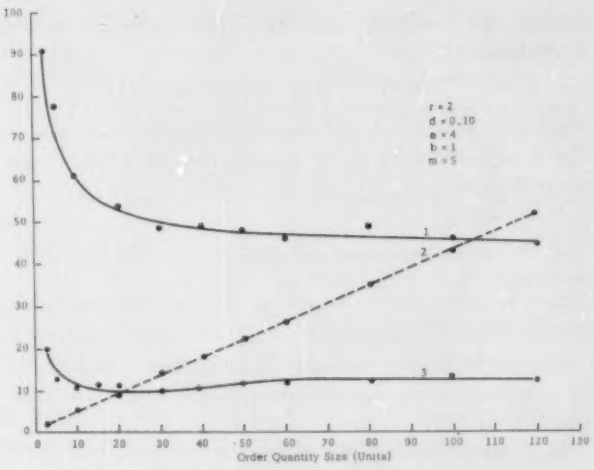

FIGURE 2. The Effect of Order Size on: 1. Facility Utilization Rate (percent), 2. Average Inventory per Item (units), 3. Proportion of Lost Sales (percent).

An examination of the data plotted in Figure 2 indicates the inventory system behavior can be predicted approximately by the following relationship

$$I \approx r + q/2 \qquad \text{Eq. 2.}$$

Note that the right-hand side of Eq. 2. constitutes an upper-bound upon the average inventory since it neglects the effect of any demands during the replenishment interval. The data in Table 1 serve to illustrate this approximation formula at two other reorder levels.

Also, note in Figure 2 that if we neglect the possibility of lost sales, the average facility utilization rate is as follows:

Percent Facility Utilization

$$\approx \left(\frac{\text{number of}}{\text{stock items}}\right)\left(\frac{\text{order arrival rate}}{\text{order servicing rate}}\right)$$

$$\approx m\left(\frac{d/q}{1/t}\right)$$

$$\approx m\left(\frac{d/q}{1/(a+bq)}\right)$$

$$\approx md\left[(a/q)+b\right]. \qquad \text{Eq. 3.}$$

TABLE 1

Average Inventory per Stock Item

Order Size	Approximation formula Eq. 2.	Simulation Data	Approximation formula Eq. 2.	Simulation Data
	$r=0$		$r=8$	
5	2.5	2.24	*	*
10	5.0	4.48	13.00	10.71
20	10.0	8.78	18.00	14.67
40	20.0	17.47	28.00	22.57
60	30.0	26.39	38.00	30.14
80	40.0	35.04	48.00	38.95
100	50.0	43.34	58.00	47.00

* Order sizes are always constrained to be greater than the reorder point.

Or with the parameter values in Figure 2: percent facility utilization

$$\approx 5(.1)[(4/q) + 1] = .5.$$

Note that because of the effect of lost sales, relationship Eq. 3. constitutes an *upper* bound upon the actual facility utilization rate.

In summary:

1. The average inventory increases linearly with the reorder quantity q.
2. The facility utilization rate tends toward an asymptote slightly below mdb.

The proportion of lost sales tends to fall in magnitude to a minimum of approximately 10% and then rises slightly.

B. *Tests to indicate the effect upon average inventory levels and the percentage of lost sales when both the reorder level "r" and the order quantity q are varied.*

Figure 3 depicts the relationship between "lost sales" and average inventory levels when both r and q are varied. Figure 3 indicates that with small order quantities q, the variations in r have a dramatic effect upon the percentage of "lost sales," but that when order quantities become large, variations in r have only a small effect. Furthermore, over the entire range of variations that we have examined—adjusting q and r simultaneously so as to hold average inventory constant—the higher the value of r, the lower the percentage of lost sales. In other words, a given investment in "safety stock" r always reduces the lost sales percentage by more than a similar investment in "order cycle stock" q. This seems to hold true regardless of the indirect effects of the order quantity upon delivery lags.

Note one qualification: We always require that $q > r$. This particular constraint is apparently operative at all of the "efficient points: in Figure 3, that is, the points of minimum lost sales at a given level of average inventory.

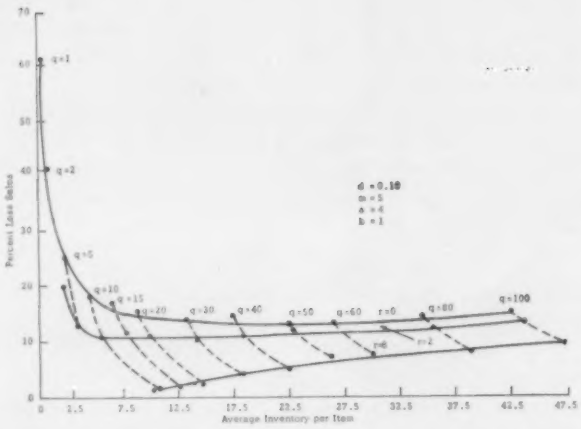

FIGURE 3. The Relationship of Average Inventory and Percent of Lost Sales for Various Values of r and q.

$$= (d/q) \div (1/t) = \frac{dt}{q} = \frac{d}{q}(a + bq)$$

The correspondence between the machine servicing model and the production inventory model may be summarized as follows:

Machine Servicing Model	*Production Inventory Model*
m = Number of machines.	m = Number of inventory items.
n = Number of machines not working.	n = Number of inventory items at or below their reorder level.
λ/u = servicing factor.	ρ = servicing factor.
Single repairman.	Single production facility.
Negative exponential distribution of time to breakdown.	Negative exponential distribution of time to reorder when $q = 1$, $r = 0$.
Negative exponential service time distribution.	Negative exponential manufacturing time distribution.
Priority rule; first come, first served.	Priority rule; first come, first served.

In the Palm-Feller model, m machines are serviced by a single repairman; a machine *is not working* when it breaks down, and it requires service by the repairman. If a machine is not working, it is either being repaired or waiting to be repaired.

Here there are m different inventory items in the system whose order quantities are processed by a single facility. An inventory item is in the breakdown state when its inventory is at or below its reorder level and an order quantity is outstanding at the service facility. This order quantity is either being processed or else waiting to be processed. That is, we say that the system is in state E_n, if n of the inventory items have order quantities out-

ANALYTICAL METHODS AND SIMULATION

For the very special case in which $r = 0$ and $q = 1$, this production and inventory system may be handled by analytical methods directly. With r and q at these values the situation becomes identical with the Palm-Feller machine servicing model (2). In order to use the Palm-Feller analysis, we continue to postulate complete symmetry between all items in the system.

Now in our production and inventory system—as in the machine servicing model—only those stock items that lie above their reorder point can generate orders for the manufacturing facility. The mean arrival rate for these orders is $d/q = d$. The mean service rate is denoted by $1/t$, where t denotes the mean of a negative exponential distribution of service times. We then define a serving factor ρ where: ρ = mean arrival rate/mean service rate

TABLE 2

Probabilities for p_n for the case
$\rho = (d/g) + (1/a + bq) = 0.50$
$m = 5$ $a = 4$
$d = 0.10$ $r = 0$
$b = 1$ $q = 1$

Order quantities being serviced or waiting to be serviced n	Order quantities waiting to be serviced	p_n
0	0	0.0370
1	0	0.0920
2	1	0.1835
3	2	0.2750
4	3	0.2750
5	4	0.1375
		$\sum_{n=0}^{m} p_n = 1.0000$

p_0 = probability of facility idle time = 0.0370.
w = expected number of orders waiting to be serviced

$$= \sum_{n=1}^{m} (n-1)p_n = 2.1100.$$

$p_{l.s.}$ = the proportion of lost sales

$$= \frac{\sum_{n=0}^{m} (n)p_n}{m} = 0.6230.$$

standing at the facility. For $1 \leqq n \leqq m$, this means that one reorder quantity is at the facility being processed and $n - 1$ order quantities are in the waiting line. In state E_0 all inventory items are above their reorder level, and the production facility is idle.

It is well known that this model leads to the following set of recursion relations for the steady-state probabilities, p_n of state n:

$$p_n = (m)_n(\lambda/u^n)p_0. \qquad \text{Eq. 4.}$$

where $(m)_n = (m)\ (m-1)\ \ldots\ (m-n+1)$. The value of p_o follows from the condition

$$\sum p_n = 1,$$

and is equal to the probability of the facility being idle.

By this method an analytical solution for describing the activity at the production facility was obtained, and compared with the results of the simulation data obtained under the same conditions. The only valid comparison can be made when $r = 0$ and $q = 1$. With $r = 0$ and q a positive integer, the order arrival times then follow a gamma distribution for the inventory model. The Palm-Feller model is no longer applicable in this case, but provides a surprisingly close approximation.

TABLE 3

Values of Average Queue Size, Probability of Facility Idle Time, and Probability of Lost Sales for various values of q, when $r = 0$, $d = 0.10$, $a = 4$, $b = 1$, and $m = 5$.

	Simulation Results			Palm—Feller Model			
Order Size	w	p_0	$p_{l.s.}$	$\rho = \lambda/\mu$	w	p_0	$p_{l.s.}$
$q = 1$	2.0900	0.0376	0.6124	0.5000	2.1100	0.0370	0.6230
$q = 2$	1.2300	0.1468	0.4134	0.3000	1.2700	0.1392	0.4260
$q = 5$	0.5933	0.3297	0.2534	0.1800	0.5964	0.3282	0.2525
$q = 10$	0.3617	0.4332	0.1834	0.1400	0.3863	0.4332	0.1867
$q = 15$	0.3383	0.4664	0.1737	0.1267	0.3189	0.4737	0.1721
$q = 20$	0.2817	0.4886	0.1548	0.1200	0.2895	0.4953	0.1550
$q = 30$	0.2700	0.5264	0.1425	0.1133	0.2587	0.5174	0.1491
$q = 40$	0.3150	0.5406	0.1492	0.1100	0.2451	0.5288	0.1429
$q = 60$	0.2617	0.5525	0.1355	0.1068	0.2317	0.5401	0.1396
$q = 80$	0.2620	0.5538	0.1387	0.1050	0.2232	0.5461	0.1354
$q = 100$	0.2883	0.5420	0.1438	0.1040	0.2218	0.5500	0.1340

The comparisons between the two methods were based on the following measures:

1. p_0, the probability of facility idle time.
2. w, the expected number of order quantities in the waiting line.
3. $p_{l.s.}$, the proportion of lost sales.

Table 2 shows a sample calculation with Feller's formulae for the values of p_0, w, and $p_{l.s.}$. The two methods turn out to be surprisingly close to each other. For example, in the case of w, expected queue length, the discrepancy is less than 1%.

Table 3 compares the two methods at values of q varying from 1 to 100. The close agreement between the two methods suggests that the negative exponential assumptions for arrival rates is not only an analytical simplification, but that it also holds up well for lower variance situations, for example, the gamma distribution.

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Comments on "An Experimental Evaluation of the Validity of Predetermined Elemental Time Systems"

by JOHN B. TAGGART

Vice President, The Work-Factor Company, Inc.

ACCURATE measurement of the work content required to produce the goods and service mankind requires is one of the most important single responsibilities of the modern Industrial Engineer. His ability to do it well affects the productivity of nations. For this reason, progressive Industrial Engineers for more than forty years have assiduously sought new ways and new means to increase their ability in this respect.

Recently the editors of the *Journal of Industrial Engineering* forwarded us the proofs of an article about to be published. It was entitled "An Experimental Evaluation of the Validity of Predetermined Elemental Time Systems," written by two German experimentors, Heinz Schmidtke and Fritz Stier and subsequently was published in the May-June issue of the *Journal*.

Recognizing the importance of labor measurement, the editors of the *Journal* asked us for comments concerning the findings of the experimentors as stated in the article. We understand requests for comments have been submitted to other engineering firms having major positions in the field of predetermined motion time systems. We wish to commend the editors of the *Journal* for their sincerity in carefully presenting material so that good, not harm, will result from the data which they publish.

The Work-Factor Company hopes the comments set forth in this article, will add to the understanding of the industrial world regarding such systems. We have no wish to discredit the experimentors Schmidtke and Stier, nor the results of their experiments. Rather, our intent is to prevent misunderstandings and confusion which might well arise in the minds of persons not familiar or experienced with the use of predetermined time systems.

The oldest predetermined elemental time system extant dates back some forty years. The Work-Factor System has been widely applied since 1946; other systems came into being thereafter. While mere age or history of technique is of no significance unless useful accomplishment has occurred, we stress that industry has, in fact, successfully used predetermined elemental time systems for many years. At this writing many unions consider predetermined elemental time systems fair and accurate; all industrially motivated countries of the world use predetermined elemental times in some form; and most competent Industrial Engineers now believe that without them, very little further progress in the science of labor measurement can be expected.

Because of the long successful history of predetermined elemental time systems, an evaluation of the article by Schmidtke and Stier must be presented as a comparison between several decades of "documented success" versus "an experiment."

The importance of the concepts involved makes it desirable to set forth a statement of the obvious requirements for valid evaluations. To properly evaluate a technique as complex as any one of the predetermined elemental time systems (Schmidtke and Stier have complicated their problem by evaluating three—WF, MTM, and BMT) requires:

1. A thorough understanding of the subject under evaluation.
2. An environment conducive to controlled experiments which isolate the needed information.
3. Data accumulation in sufficient quantity to support constructive conclusions.
4. An analysis of the data which avoids confusion of the significant with the insignificant.
5. Mature experience in the interpretation of the accumulated and analyzed data.

We have presented the foregoing requirements because it has not been apparent to our staff that they were met in the Schmidtke-Stier experiments. For the reader's use in understanding this article prepared by The Work-Factor Company, it may be helpful to set forth the major objectives and characteristics of a sound labor measurement technique. They are:

Objectives

1. Accuracy.
2. Consistency.
3. Ease of application.
4. Understandability of all involved.
5. Universal applicability.

Characteristics

1. Based on extensive data for average conditions.
2. Fully field tested and modified to meet average conditions.

3. Adequately described with firm rules and procedures of application for average labor measurement requirements.

4. Organized and readily applied from tabular values for average conditions.

It is of course, well established that the foregoing criteria must apply to any sound labor measurement technique. Within this framework, the author of this article believes the following comments are pertinent and will be helpful to the readers' evaluation of "An Experimental Evaluation of the Validity of Predetermined Elemental Time Systems."

COMMENTS ON CONCLUSIONS OF SCHMIDTKE AND STIER

Since Schmidtke and Stier have summarized their interpretation of the results of their experiments into conclusions, our comments approximately follow their sequence. We have restated each of their conclusions as we have read them in their article, and have supplied our view of their conclusions.

Schmidtke-Stier Conclusion Number 1: A factor must be added to predetermined elemental times to convert them to standard times.

Work-Factor Comment: It is quite customary to deal in terms of operation cycle times which do not include allowances for fatigue and delay and, if applicable, incentive. The literature on Work-Factor clearly sets forth that all Work-Factor Time Values are Select Time. Work-Factor Select Time is defined as follows:

> Select Time is the time required for the Average Experienced Operator working with good skill and good effort (commensurate with physical and mental well being) and under standard working conditions to perform one work cycle, or operation, on one unit or piece, according to prescribed method and specified quality. The Select Time includes no allowance for personal needs, fatigue, environmental unavoidable delays, or incentive payment.

Hence, by definition, when an operation time has been established by means of Work-Factor Select Time, it is necessary to add an allowance for fatigue, personal time, unavoidable delays, and (if applicable) incentive. Once such factors have been determined and agreed upon for a specific factory or industry they remain constant from there on and are completely free of decision making on the part of the Industrial Engineering staff.

Schmidtke-Stier Conclusion Number 2: Motion direction is not considered in any published predetermined motion time system. They state their experimentation proves that motion direction is a factor.

Work-Factor Comment: Work-Factor Select Time Values have been established for the average experienced operator working under average conditions. The original research investigated the significance of motion direction (up, down, sideways, to and from the body, etc.) and determined that, in view of the other variables which must be considered in establishing production standards, motion direction was of relatively minor importance. When the Work-Factor research data were accumulated, an average of all directions of motions was recorded in the readings, hence, the Work-Factor predetermined elemental times include average times for motions in any direction.

Schmidtke-Stier Conclusion Number 3: Insufficient time differentiation is made for weight.

Work-Factor Comment: Many thousands of recordings were made by the originators of the Work-Factor System to learn about the weight-time relationships in manual motions. Three separate investigations were made over a period of about ten years, each independent of the others. The third and final check brought about a minor modification which was made effective in 1945. Operation cycles have been established with Work-Factor involving all weights encountered within limits of efficient industrial practice. There has been no dissatisfaction on the part of workers or managements since that time. We believe the test of usage must be overriding in this case.

When the Japanese first began to use Work-Factor some years ago, they had doubts as to whether the Work-Factor values for weight would apply to the Japanese people who, on the average, may not be as large and as strong as the American workers. Therefore, they undertook a series of experiments in a number of Japanese plants to check the Work-Factor time-weight relationship. The Japanese concluded that the Work-Factor values for weight were adequate and suitable for use with Japanese workers.

Schmidtke-Stier Conclusion Number 4: The interdependence of preceding and subsequent work motions is not taken into consideration in any of the predetermined time systems.

Work-Factor Comment: With respect to the Work-Factor System, we can only state that this is completely incorrect. Work-Factor motion times were established by the procedures described in the paragraph which follows:

Some 1100 operators were studied during the original research. The observers worked in teams of two. One observer made recordings while the other made the timings. When the study forms were half completed, the observers changed boards and continued the study until completed. This gave both observers an opportunity to time and record. The research procedure was to list all the elemental motions involved in the operation cycle, identify them in terms of nomenclature established for the project, and then to time each motion individually, obtaining twenty readings for each such motion per operator motion. An operation cycle of one-half minute took about eight hours to complete. Interspersed between the recordings of motion times, overall total cycle times for the operation were recorded. When the study was complete and totaled, it was required that the total of the average individual elemental times be equal to the average of the total cycle times to within five percent. If this was not the case, the study was rejected in its

entirety. Because of this thoroughness, it is known that no time has been omitted from the Work-Factor tables of elemental times. Hence, complete and absolute recognition has been given to the time effect on preceding and subsequent motions in all cases. Over the years, it has been conclusively demonstrated for practical purposes, that the Work-Factor motion time values are interchangeable from cycle to cycle.

Schmidtke-Stier Conclusion Number 5: Predetermined elemental time systems neglect the effect of "repetition frequency" on motion times.

Work-Factor Comment: With respect to Work-Factor this is not true. No doubt Schmidtke and Stier, through lack of knowledge of Work-Factor, have made this misstatement. The Work-Factor motion times in the Detailed Table have been used for many years to establish correct production standards for mass production work. It is true, there are situations where repetitive motions occur. The Work-Factor System recognizes circular motions, short motions, stroke motions (hammer blows) and a variety of other rather special kinds of repetitive motions. The Work-Factor System includes time values for all of these, separate and apart from the Detailed Table of motion times. These time values have been in use for some time. No doubt, Schmidtke and Stier were uninformed about this.

Schmidtke and Stier Conclusion Number 6: The sum of the times required to perform motion elements is not identical to the whole motion pattern. In other words, the whole may be greater than, or less than, the sum of the parts.

Work-Factor Comment: We believe this is thoroughly answered under our comment to Schmidtke-Stier Conclusion Number 4.

Schmidtke-Stier Conclusion Number 7: Variations in operation times established by predetermined elemental time systems lead to errors much larger than those generated by stop watch time study.

Work-Factor Comment: Here again we presume that Schmidtke and Stier speak from lack of knowledge. Throughout this article we wish to remind our readers that our comments are not meant to be derogatory. Simply, we hope to state facts. Since 1946, the Work-Factor Company has serviced industry world wide with training and application of Work-Factor Time Standards. Part of our planning for proper programs in each individual company is always a survey in each plant to determine the level of existing production standards prior to installation of Work-Factor. The overwhelming mass of data demonstrates that variations in output standards established by conventional stop watch techniques exceed variations where the Work-Factor System is used by some ten to one. The data which support this statement would, we are sure, more than convince Schmidtke and Stier that their fears for predetermined elemental time systems are unfounded.

While it is agreed that individual time study engineers in one plant may learn to level stop watch studies to within perhaps five percent of each other on a limited variety of operations, generally, this is not the case throughout any industry and industrial area in any country. It is a known fact that variations in the concepts of "normal" between engineers and between companies may differ as much as plus or minus fifty percent. We believe Schmidtke and Stier have lost sight of this inherent defect in stop watch time study. Apparently they do not subscribe to the fact that any organized approach gives better overall results than the stop watch and human judgment.

Schmidtke-Stier Conclusion Number 8: Predetermined elemental time systems are designed to take the place of the traditional time study method in industry.

Work-Factor Comment: This is correct with respect to the Work-Factor System. The primary motivation for the original Work-Factor research begun in 1934 was the need for a technique to replace the stop watch and the judgment factor of conventional time study. After some four years of research, the system known as Work-Factor evolved. It was tested and applied for a long period and finally made available for general use in industry in 1946. The originators and developers have constantly dedicated themselves to perfecting the Work-Factor System for precise and accurate standards on mass production, medium quantity production, short production, and all other manual and mental work which can practically be measured. More than fifty percent of all Work-Factor applications provide time standards for incentive pay plans.

We cannot speak with full authority for the other systems, but it is our understanding that MTM, for example, originally was not designed to replace other time study and labor measurement techniques.

Schmidtke-Stier Conclusion Number 9: The concept underlying predetermined elemental time systems is identical with that of elemental physiology and elemental psychology. Because of this, the techniques lack adequate dynamics and have suffered because of the discredited approaches of elemental physiology and psychology.

Work-Factor Comment: The Work-Factor System, from its inception on through its many phases of development, has never been static. It is true that, when certain aspects have been demonstrated incontestably over a long period, it has appeared fruitless to check them further. However, rules of procedures, descriptive terms, and new variations of time applications are continuously being added to the Work-Factor System. While the Work-Factor staff does not value "change for the sake of change" it is anticipated by the Work-Factor Company that this dynamism of the system will not diminish, but increase.

Schmidtke-Stier Conclusion Number 10: An excessive

demand over a long period of time may be injurious to health.

Work-Factor Comment: While true, this statement appears irrelevant to the question of validity of predetermined elemental time systems. However, since there could be an implication, we comment that the definition of Work-Factor Select Time includes a statement to the effect that the work pace expected by Work-Factor requires that the operator be physically, mentally, and comfortably able to maintain his or her work pace throughout the working day and throughout the working year. We consider it obvious that, were this not the case, Work-Factor would have been discarded long since through the efforts of dedicated labor unions. On the contrary, many unions (along with the managements of their respective companies) praise the fairness and equity of Work-Factor Time Standards.

Schmidtke-Stier Conclusion Number 11: "Physiologically optimum" motion times, under certain conditions are the same as "normal times."

Work-Factor Comment: We believe that Schmidtke and Stier have an inadequate sample of work motion times for two reasons.

1. Limited data taken from a limited number and variety of operators in a restricted environment.
2. Many of their timings were of individual motions which were not part of a total motion cycle.

For these reasons, we suggest that any comparison between the experimentors' findings and the statistically compiled Work-Factor System (based on some 17,000 individual motion time studies) is not valid.

Schmidtke and Stier have generated discrepancies in their evaluation between the various experiments and the various predetermined time systems because of their apparent misunderstanding of the "normal" concept. They have used the words "physiological optimum motion time" which they say under certain conditions can be considered as "normal." They further state that: "The motions are well practiced and more or less performed without conscious control and without being directed by higher centers of consciousness and without being affected in any way by other variables or influenced by wage incentives." This seems a reasonably clear use of the "normal" concept.

This concept was applied throughout the Schmidtke and Stier experimentation involving individual motion times. However, in the studies involving their measurement of "way-time," they clearly state "experimental subjects had to go through a training period of some time until no further improvement of their skill could be realized." *Motions were made with such speeds that all targets could be struck without missing.* From this, it would seem that the operators were moving at the maximum speed with which they could accurately attain the target, and were so practiced that no further improvement in either skill or speed was possible. Accordingly, this does not fit the definition of "normal" time and would indicate that the operators were working at either an incentive speed or perhaps even at maximum speed.

These two approaches are not reconcilable. This may be one of the reasons why Schmidtke and Stier conclude that, in certain types of operations and work elements, predetermined times are loose.

Schmidtke-Stier Conclusion Number 12: "No difference is made between motions involving predominantly the forearm and the motions involving the whole arm."

Work-Factor Comment: Here again is an incorrect assumption. The Work-Factor System compensates for the portions of the arm involved as follows:

The longer the motion, the more of the arm which must be involved. The change in time, because of the amount of required arm extension, was timed in the original research.

Since industrial work cycles should be established primarily for convenience and efficiency of operation, the use of the forearm stiffly extended in performing work is extremely limited. If and when this does occur, the Work-Factor System includes values which are applied. We note here that the number of times this has been encountered in our experience is so limited that our staff does not recall the last time the values were required.

Schmidtke-Stier Conclusion Number 13: It is clear that the time values for MTM and Work-Factor motions involving no weight are 25 to 30 percent lower than the optimum values found in their experiments. They suggest that this difference may possibly be explained by the fact that the concept of MTM and Work-Factor is based on a different performance level than their concept used in establishing their optimum physiologically defined normal performance.

Work-Factor Comment: There is no valid means of using Schmidtke and Stier's findings. Work-Factor Select Time is not on the same performance level as MTM normal times. As stated in an earlier definition in this article, Work-Factor Select Time is based on a work pace for the average experienced operator working with good skill and effort. It is our understanding the MTM tabular values are for the average experienced operator working with average skill and average effort. We also suggest that Schmidtke-Stier's data are of such a small sample that, regardless of their concept of "physiologically normal" their sample is too small to be valid as a reference against the Work-Factor data which have several decades of successful usage and four years of data accumulation in the original research.

Schmidtke-Stier Conclusion Number 14: It is proven that the precision, required to touch a target, produces a decelerating effect on the following motion. The result of this series of experiments leads them to the conclusion that it is necessary for the integration of an additional factor in the elemental time tables to compensate for this increase in time.

Work-Factor Comment: Our research data demon-

strate that preparation in advance of approaching the target and finally touching the target require care and accuracy and hence, more time than if no target is involved. However, our data also indicate (and a large amount of it) that once the target has been reached, the need for care and precision ceases and the next motion proceeds without significant influence from the previous target. The reader can visualize this by considering a motion pattern wherein it is required to test a hot object by touch. As the hand approaches carefully to touch it with minimum pressure (so there will be minimum discomfort) much time is consumed. However, when the hand has touched the hot object, its withdrawal is extremely rapid without thought or care because of the previous precise approach motion. While this is not a much used industrial motion, we believe it illustrates a basic fact concerning work.

GENERAL COMMENTS ON THE SCHMIDTKE AND STIER ARTICLE

We wish to reemphasize our desire to be constructive rather than destructive in our reply to the *Journal* editors' request for comments on the Schmidtke and Stier article. While being obliged to be blunt in some comments, we hope that it has been good for all concerned.

We also offer other comments which, while not so specifically related to conclusions reached by Schmidtke and Stier, are important in the independent evaluation of their work.

1. Many conclusions drawn by Schmidtke and Stier are based on the timing of individual motions, not part of actual industrial operation cycles. We believe this is a dangerous experimental procedure upon which to base conclusions; we believe that a motion must not be considered individually but must be considered as part of the whole operation cycle in which it is used.

2. For clarification we must point out the application of the Work-Factor System to experiment described in Figure 20 and documented in Figures 21, 22, 23, 24, 25, and 26, of the Schmidtke-Stier article appear incorrect. Based upon the illustration in Figure 25, we believe their application of Work-Factor is in error in respect to three subelements:

a. Grasp—it would appear that the analyst has used an *F*1 grasp requiring 16 Work-Factor time units (1.6 milliminutes). The movement should be analyzed as a pinch grasp at the end of a reach. The numerical value then would be 1/2*F*1 requiring 8 Work-Factor time units (8 milliminutes).

b. In the case of release following assemble, it appears that a full *F*1 release of 16 units (1.6 milliminutes) was used whereas a gravity type release of 1/2*F*1 of 8 units (.8 milliminutes) should have been used.

c. Based upon the description of the experiment as we understand it, we know of no reason why the reach preceding the grasp of the pin should require both steering and definite stop (*SD* Work-Factors). According to the Work-Factor rules, this motion requires only a definite stop (*D*) Work-Factor. At an 8 inch distance the time difference would be a decrease of 16 units. Thus at 8 inches there is a total error of 32 units (3.2 milliminutes) or approximately 16 percent.

d. Throughout the discussion it is noted that Work-Factor and MTM times are treated as being comparable. It would appear that the authors are not aware of the fact that times shown in MTM tables are "normal" whereas Select Times read from the Work-Factor Table are at an incentive work pace. There may be other misunderstandings, also.

3. We have suggestions in respect to the translation from German to English. We believe the words "way-time" would be better translated as "travel time," "reach time," "move time," or "transport time." We notice in several places the words "gripping distance" have been used. We believe that this is incorrect terminology and that the translator meant "motion distance" (reach, move, or transport). "Gripping distance" in the Work-Factor System refers to the distance between the point at which a plug or other object being assembled is held by the hands and the point at which the object makes insertion.

SUMMARY

The Work-Factor Company still employs some of the engineers involved in the original research which began in 1934, and in later development and testing of the system. In discussing the Schmidtke and Stier article, these engineers were reminded of the many unfruitful avenues pursued during the four-year research period in an effort to find an approach which might solve the extremely complex labor measurement problem. It appears to us that because of their dedication, Schmidtke and Stier would have been good adjuncts to the staff which performed the original Work-Factor research, and it is regrettable that this was not the case. Their work is obviously one of sincerity.

In summary, it might be helpful to review the extent of effort which has gone into the preparation of the now internationally known Work-Factor System. Its creation essentially was as follows: original research begun in 1934 and concluded approximately 1938; field testing begun in 1938 and concluded approximately 1945; wide industrial application begun in 1946 and continuous since that time. As previously stated, all industrial countries of the world use Work-Factor to some extent, many of them extensively for labor measurement and incentive pay with considerable satisfaction. The Work-Factor Company supervises all Work-Factor installations worldwide with its own engineers; and has offices or representatives in England, France, Japan, Germany, Holland, Australia, Brazil, United States, Canada, etc. In the United States, two prominent Industrial Engineering organizations assist in maintaining the high standard which has been established in all Work-Factor applications throughout the world. These organizations are the Work-Factor Associates of the Midwest (WFAM) and the Work-Factor Associates of the East Coast (WFAEC). There have been a variety of articles published concerning Work-Factor, the earliest dating back

to 1945 (1). The system was well described in the *Industrial Engineering Handbook* published in 1956 (2).

In September 1961, a complete Work-Factor textbook will be published by McGraw-Hill Book Company, Inc. (3). Perusal of this publication should correct in the minds of Schmidtke and Stier many of the fallacies which have arisen because of their lack of knowledge of the Work-Factor System.

Work-Factor again wishes to express its gratification at the integrity demonstrated by the *Journal* editors in their attempt to promote and propound a sound philosophy for the advancement of the science of Industrial Engineering.

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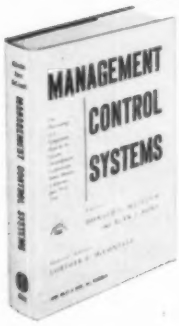

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Simulation in the Application of Wage Incentives to Multiple Machines

by **H. J. JOHNSON**

Assistant Chief Industrial Engineer, Machinery Division, Cabot Corporation

and **S. S. SMITH**

Industrial Consultant, Rath and Strong, Incorporated

SIMULATION, a relatively new technique, should become a basic tool of Industrial Engineering. Many articles have been written on the use of simulation in the solution of complex problems and the training of executives through game playing. Few articles, however, have been written showing how it can be used in solving simpler, more routine problems easily and quickly. In the following problem, work load and interference were obtained by simulation rather than lengthy studies of the actual machines in operation.

A group of six Farrel-Birmingham gear generators were to be put on wage incentives as part of a plant wide one-for-one individual incentive installation. The initial work situation was as follows:

Machine Number	*Machine Size*	*Operator*	*Product*
1	Small	A	24 sizes of pinions
2	Small	A	Gears—30 Sizes
3	Small	B	Gears—Interchangeable between these machines
4	Small	B	Gears—Interchangeable between these machines
5	Medium	C	Gears and Pinions, 10 sizes
6	Large	C	6 sizes of gears

In applying incentives to the gear cutters it was necessary to answer such questions as:

What is the work load per operator?

How many machines should be assigned to each operator?

What would be the advantage in the operators assisting one another?

Is the work load significantly different from one machine to another?

Will a machine interference factor be needed and if so, how much?

Will individual incentives be practical or will it be necessary to make a small group application?

In placing the gear generators on incentives the goal was a balance of the following factors:

Optimum utilization of the machines which could be a production bottleneck.

High, balanced loading of the operators.

Maintenance of a uniform high quality gear.

Optimum life of the cutter sets, the total annual cost of which was as much as the direct labor cost of operating the machines.

Timestudies were taken of the machine group over a period of four weeks to set standard times for all elements of work. Trials were made of various cutting conditions and Operation Sheets were written describing the preferred method of cutting each size of gear and pinion on the various machines. The work time of the operators was separated into three categories.

1. The minimum work time to produce a gear or pinion keeping the machines constantly in operation.
2. Work per gear or pinion that is done as fill-in or internal work when the machines are in cutting cycle but do not need attention.
3. Available idle time when the machines are in cycle but no work remains to be done.

The ratio of first and second category work time to the entire time to machine a lot of gears or pinions was defined as Percent Work Load. Interference was defined as occurring when work of the first category was required simultaneously on more than one machine.

In order to solve for work load and interference it would have been necessary to timestudy the machines and operators for a number of weeks to get stable averages. It would have been necessary to repeat this timestudy for each different work assignment, such as one operator to each two machines, operators assigned as a team to various numbers of machines, etc. Such a study of the machines and operators would have required an estimated minimum of 32 timestudy observer weeks as well as some disruption of the production schedules to study various work assignments. A work sampling type study could have been carried out for an estimated one third of this expenditure of time (1) (5) (6).

It was felt, however, that the work situation could be mathematically simulated (1) (3) (5) (7) (8). Through simulation data could be quickly collected similar to that obtained from a work sampling study. Various combinations of machines and operators could be tried to check for work load and interference. An additional advantage was that the analysis of the data was quite similar to that of a work sampling study. It was felt that satisfactory answers to the initial questions could be obtained in less than two timestudy man weeks.

SIMULATION

The simulation of the multiple machine assignment to determine work load and interference was done in two steps. First, a mathematical model of the work situation was set up and second a work sampling type study of the model was simulated in the same manner as the actual machines and operators would be observed.

In our first mathematical model of work load Category 1 work time was separated from total time to complete a lot of gears or pinions for each machine. This was possible as fill-in work, Category 2, was low as a percent of the total cycle times. Also the operators could not be loaded so that they had more than 5 percent interference of machines in cycle. If the cutters were not watched carefully and the cuts fed in as required, the life of the cutter sets could be greatly reduced and poor quality gears would result.

Using the methods from Operation Sheets, work times from standard data and a record of the parts going over each machine an average percent work time was obtained for each machine. Various combinations of work assignments were simulated in the following manner.

Assume the parts going over Machine Number 1 have an average Work Time of 12 percent and 88 percent Open Time, Machine Number 2, 25 percent Working Time and 75 percent Open Time. With a single operator attending these two machines Table 1 can be set up.

TABLE 1

Machine	Number 1		Number 2
Working Time	12%		25%
Open Time	88%		75%
Random Numbers for Work	01–12		01–25
Random Numbers for Open Time	13–100		26–100
(Random numbers selected from table and placed alternately under machines)	91		61
	38		53
	89		09W
	05W	(Interference)	14W
	64		80
	57		54
	31		67
	67		85
	88		23W
	19		28
Observations or Sample Size	10		10
Occurrence of Work	1		3
Percent of Work	1/10 = 10%		3/10 = 30%
Occurrence of Interference		1/10 = 10%	
Work Load for a Single Operator		4/10 = 40%	

Numbers taken from a random number table are used to simulate observations of the operations. Using the random digits from 01 to 100 (00 represents 100) the digits 01 to 12, inclusive, occur 12 percent of the time leaving the digits 13 to 100 to occur 88 percent of the time. The occurrence of the random digits 01 to 12 can therefore be used to signify manual work on Machine Number 1. The occurrence of the digits 01 to 25 will signify that work is required on Machine Number 2. If numbers less than 12 and 25 are selected from the table consecutively both machines require work simultaneously, the condition of interference.

This simulation quickly produced overall load and interference figures, but proved to be over simplified. It was desirable to explore the range of interference and load as the product mix changed from combinations of small gears and pinions being cut to a predominance of large parts. The simulation was therefore carried one step further.

An examination of the cutting times of the parts going over each machine revealed that they fell into three or four natural groups of cutting times per piece. The pieces with approximately the same cutting time were grouped for each machine and the average percent of working time computed for each group. It was then necessary to compute the percentage occurrence of each group which depended upon the lot size and running time.

Table 2 is similar to Table 1 with the exception of several categories of work time for each machine. For example, 70 percent of the parts going over Machine Number 1 require 27 percent work time, 20 percent of the parts need 18 percent work and the remaining 10 percent require 35 percent work.

TABLE 2

Machine / Condition	Number 1 Work Group	Number 1 Work	Number 1 Open Time	Number 2 Work Group	Number 2 Work	Number 2 Open Time
Cutting Time Work Groups with Designating Random Numbers	1 (10%)	35% 01–35	65% 36–100	1 (10%)	23% 01–23	77% 24–100
	2 3 (20%)	18% 01–17	82% 18–100	2 3 4 (30%)	42% 01–42	58% 43–100
	5 6 7 (30%)	27% 01–27	73% 28–100	5 6 7 (30%)	34% 01–34	66% 35–100
	8 9 0 (70%)			8 9 0 (30%)	27% 01–27	73% 28–100
	(100%)			(100%)		

On Table 2, random numbers are taken in groups of three. The first digit is used to signify the cutting time group with the remaining pair of random digits signifying work or open time as in Table 1. The random number 823, for instance, on Machine Number 1 signifies parts of the type that require 27 percent manual work. The 23 simulates work as it is within the range 01 to 27. The random digits 361 for Machine Number 2 signify work of group 3, while the 61 indicates open time. Random numbers were selected for several days for each of several work assignments and product mixes.

RESULTS

Some of the conclusions were as follows. The average work load differed quite significantly from machine to machine. With the assignment of two machines per operator the work load was light, even including internal work, but on the average interference was higher than desirable. An assignment of two men to five machines

did not give excessive interference for an average product mix if the men worked as a group. The assignment of three operators to six machines resulted in a lower machine interference and work load per operator than considered necessary. This assignment would only be practical if maximum output was required. A group incentive plan, one for each shift, was used to promote working as a team. Interference of 5 percent was substituted for the regular 5 percent personal allowance as the operators are expected to take personal time during the available idle time.

CONCLUSION

Some of the results of this simplified simulation in this example could have been more easily obtained by other techniques of statistics and probability. Simulation, however, is considered to have been easier to understand by timestudy personnel and proved to be direct, convincing, flexible, quick and effective. Once understood similar simulation techniques can be applied to many other Industrial Engineering problems in a short time, at low cost and with a minimum of higher mathematical knowledge. The same technique may be applied to more complex problems. Several distributions of random numbers are available to increase the flexibility (2) (4). If especially lengthy, varied or accurate solutions are required, the actual work of the solution may be readily transferred to punch cards in the average machine tabulation department.

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PRESIDENT'S COMMENTS . . .

President of the American Institute of Industrial Engineers, 1961-62

by **JACK F. JERICHO**

Institute Membership Qualifications— Need for a Change?

OVER the years many factors have contributed to the overall success and growth of the American Institute of Industrial Engineers. But if someone asked what one single thing may have made the most significant contribution to this success, I think most of you would agree on consistent and high membership standards. However, a society representing a profession which is changing as rapidly as Industrial Engineering must always be alert to the need to revise its membership qualifications. All of us agree that we should never dilute our membership requirements, because the strength of any society depends to a great degree on the professional eminence of its membership.

BACKGROUND REVIEW

During the past three or four years, many questions have been asked about our membership qualifications. Chapters throughout the country have felt that, in some instances, we are too restrictive and keep men out of the organization who should be members; on the other hand, many feel that men who are not qualified have become members.

In the latter part of Frank J. Johnson's administration and the early months of Alex W. Rathe's, it became more and more obvious to the Institute Board of Trustees that a complete study of our membership qualifications should be made. In view of this, the Membership Board of Review, chaired at that time by W. E. Fourqurean and later taken over by E. J. Palisin, was asked to make an objective review of the Institute's membership qualifications and the Membership Qualifications and Classification Manual used by the chapters.

At the Eleventh Annual Conference and Convention held in Dallas, Texas, a portion of the Chapter Presidents' meeting was devoted to the problems associated with the Institute's membership qualifications. At the conclusion of these discussions, W. E. Fourqurean advised that a comprehensive study was being undertaken and the chapters would have the opportunity to submit their problems and ideas to the Board of Review for consideration. The feedback from the chapters, obtained through a comprehensive questionnaire, was very revealing and proved to be helpful to the taskforce in developing recommendations to improve and clarify the membership qualifications of the Institute.

IMPORTANT PROBLEMS

Here are some of the important problems brought to light as a result of the chapter survey as well as comments given the taskforce by many of the Regional Vice Presidents who served in 1958-59 and 1959-60:

1. Misunderstandings regarding use of Affiliate grade.
2. Possible dues inequities by using Affiliate grade for purposes other than original intent.
3. Qualifications for Associate Member inadequate. In some instances does not differentiate between Industrial Engineering or engineering graduates and men with degrees in liberal arts, agriculture or business.
4. Elimination of the word "Senior" from one of the grades of membership unpopular.
5. Qualifications too lenient for acceptance of registered Industrial Engineers and registered engineers as Members.
6. Categories of Industrial Engineering functions listed in the manual outdated, limited, and to some degree, inaccurate.
7. Scope of Industrial Engineering as presently defined in the manual too limited. Does not entirely portray the modern image of Industrial Engineering.
8. Qualifications in the manual vague, outdated, and not too comprehensive. (Manual not revised since 1957.)
9. Membership qualifications, as outlined in the manual, difficult to reconcile with the qualifications shown in the Constitution.
10. Percentage of applications sent to Membership Board of Review for processing too high.
11. Limited information available for chapters to understand what the Membership Board of Review uses in evaluating the qualifications of new applicants.

To solve these problems and not weaken the membership qualifications of the Institute presented quite a challenge to the taskforce.

PROPOSALS AND RECOMMENDATIONS

After several months of study, the taskforce submitted proposals to clarify and strengthen the membership qualifications to the December, 1960 Board of Trustees' meeting for review. At this Board meeting, the following basic principles were approved:

. . . Reaffirmed the Institute's basic policy not to dilute membership by broadening requirements for membership.

. . . Accepted in principle the desirability of an additional noncorporate grade of membership.

. . . Authorized the Executive Committee to modify and implement the recommendations of the taskforce in accordance with suggestions of the Board of Trustees, subsequent to review and recommendations from several of the Institute past presidents.

The significant recommendations of the taskforce in addition to the need for another noncorporate grade of membership follow:

. . . Develop Associate Member qualifications for men obtaining Industrial Engineering and other engineering degrees from schools not accredited by the Engineers' Council for Professional Development. (Presently, these men need as many years of actual Industrial Engineering experience as graduates in liberal arts, agriculture, or business to qualify as an Associate Member.)

. . . Re-establish the Senior Member terminology in lieu of Member.

. . . Provide safeguards to make sure that registered engineers, industrial or other, are practicing or have practiced Industrial Engineering.

. . . Clarify and modernize both the categories and scope of Industrial Engineering in the manual.

. . . Rewrite the entire Membership Qualifications and Classification Manual and the Membership section of the Constitution to assure compatibility and understanding.

. . . Develop specific credit for use by the chapters, Institute headquarters, and the Membership Board of Review for managerial responsibility over Industrial Engineering functions, college teaching, advanced degree work, etc., when reviewing an applicant's qualifications.

As a result of Board action, the taskforce contacted several of the Institute past presidents for their comments and ideas regarding the recommendations. These comments were carefully weighed, and most of them were included in the final recommendations presented to the Executive Committee in April, 1961. The Executive Committee approved the recommendations but requested some changes in terminology in the categories and scope of Industrial Engineering. E. J. Palisin and I were asked to make these changes in Detroit. The Executive Committee also instructed the Executive Secretary to prepare the Constitution changes which would have to be submitted to the Membership for approval.

CONSTITUTIONAL CHANGES

Since the meetings in Detroit, a new Membership Qualifications Manual has been prepared. The new manual will include recommendations to strengthen and clarify the qualifications, broaden the categories of Industrial Engineering, and modernize the definition and scope of the profession. The material to be included in the new manual has been sent to the present Board of Trustees for final review and comments before going to press. However, before the new manual can be used, several changes in the Constitution require approval by the membership. A ballot to vote for these changes is included in the "Institute Interests" section of this issue of the *Journal*.

In order that you may have some background information before you vote on the recommendations, I will discuss some of the significant proposals and explain how the changes will eliminate or minimize many of the problems mentioned earlier.

AFFILIATE

As most of us know, the Affiliate grade of membership, which is a nonvoting grade, was established for ". . . a person who, by scientific requirements or practical experience, had obtained a position in some profession or branch of industry or science which qualified him to cooperate with Industrial Engineers in the practice and advancement of their profession, and that he must be at least 25 years of age." Ever since this grade has been established, it has also been used for men working as Industrial Engineers who did not yet have the qualifications to become an Associate Member. For instance, any college graduate, with a degree not accredited by ECPD, whether it be in agriculture, business, or Industrial Engineering, with less than four years of actual experience in a number of recognized Industrial Engineering activities, was admitted as an Affiliate.

Let's examine the problem further. Take an individual who has just received an Industrial Engineering degree from a school not accredited by ECPD and is 22 years old. Also, consider that this school may have been preparing to ask for an ECPD inspection or it may have been a school, which by state law, could not seek accreditation. At the present, this man could not be admitted to the Institute in any grade. To further illustrate the problem, assume the individual is 25 years old. He could then be admitted to the Institute as an Affiliate but would pay $7.50 more dues per year than the Industrial Engineering graduate from a school accredited by ECPD. This individual would immediately become an Associate Member and pay lower dues for five years.

JUNIOR

To eliminate misuse of the Affiliate grade and restore it to the purpose of its original intent, the taskforce has recommended another nonvoting grade of membership to be called "Junior." Following is a summary of the qualifications for this new grade:

1. A graduate of an engineering curricula, accredited by ECPD (no Industrial Engineering option or minor), actively engaged in the field of Industrial Engineering for less than one year.

2. A graduate of Industrial Engineering or other engineering curricula, not accredited by ECPD, actively engaged in the field

of Industrial Engineering, but not meeting qualifications for an Associate Member.

3. All other college graduates actively engaged in the field of Industrial Engineering, not meeting the qualifications for an Associate Member. A candidate must have a minimum of two years of Industrial Engineering experience in two or more categories. (Credit up to one year may be substituted in lieu of experience for one year of college level engineering or physical sciences.)

4. Noncollege graduates with some or no college training actively engaged in the field of Industrial Engineering, but not meeting the qualifications for Associate Member. A candidate must have a minimum of four years of Industrial Engineering experience in three or more categories. (Credit up to two years may be substituted in lieu of experience for two years of college level engineering or physical sciences.)

In addition, the committee also included the following statement as a part of the new Junior grade qualifications:

"A Junior must qualify for Associate Member within five years or be dropped from the organization."

If this grade is adopted the dues will be $10.00, the same as presently paid by an Associate Member during his first five years in the Institute. By establishing the Junior grade, the committee feels that misuse of the Affiliate grade will be eliminated and possible inequities in dues will be minimized.

As stated earlier, the Associate Member qualifications may be inadequate. Graduates with Industrial Engineering and engineering degrees from schools not accredited by ECPD have been treated the same as graduates from any other schools, such as liberal arts, agriculture, business, etc., when considered for membership in the Institute. The taskforce has recommended that if the Institute is to provide proper guidance and assistance to graduate engineers entering the Industrial Engineering field, we must clarify our qualifications for the Associate Member grade so that these men can become voting members sooner than graduates from schools other than engineering. In order to do this, the taskforce has recommended that the following be added to the present qualifications:

1. Graduate of an Industrial Engineering curriculum not accredited by ECPD with one year of Industrial Engineering experience.

2. Graduate of an engineering curriculum not accredited by ECPD, having two years of Industrial Engineering experience in three or more categories.

REGISTERED PROFESSIONAL ENGINEERS

For several years, many chapters have felt that more safeguards were needed in the membership qualifications for registered professional Industrial Engineers and registered professional engineers other than industrial. Presently, a registered professional Industrial Engineer automatically becomes a Member upon application; a registered professional engineer other than industrial is eligible to become a Member upon application, if actively engaged as an Industrial Engineer at the time the application is filed. Following are the recommendations proposed to provide the safeguards that the Chapter Membership Qualifications Committees should have in evaluating the background of registered professional engineers:

1. Registered professional Industrial Engineer—eligible for Senior Member (if "Senior" terminology is re-adopted) upon application providing he holds, or has held since securing his registration, a responsible position in Industrial Engineering for at least one year.

2. Registered professional engineer, other than industrial—eligible for Senior Member upon application providing he holds, or has held, a responsible position in Industrial Engineering for at least two years.

INDUSTRIAL ENGINEERING CATEGORIES

Expanding the Industrial Engineering categories used by those responsible for membership qualifications throughout the country will not require Constitution changes or a vote from the membership. However, it is my feeling and that of the taskforce that each of you should know the categories which have been used in the past in evaluating new applicants and the expanded ones which will become a part of the new Membership Qualifications and Classification Manual. Before reviewing the new categories, you should examine those which have been used for several years:

- Plant layout
- Process routing
- Production control
- Quality control
- Safety engineering
- Plant engineering
- Materials handling
- Manufacturing methods
- Standard time data
- Manufacturing budgetary control
- Cost and analysis
- Estimating
- Job evaluation
- Office systems and procedures
- Sales engineering
- Tool design and control

Now let's look at the new categories developed only after careful consideration of data submitted by the chapters, comments from many Institute officers, the work of Dean Kopp's committee on professional standards, and the work submitted by Morley H. Mathewson and "The Emerging Role of Industrial Engineering," edited by Austin Weston.

Industrial Engineering experience as referred to in basic membership qualifications and on the application blank shall consist of experience in research, design, development, and installation of plans, methods, systems, and controls involved in the following recognized Industrial Engineering activities as applied to any function in any enterprise:

1. Selection of processes and assembling methods.
2. Selection of tools and equipment.
3. Design of facilities, including layout of buildings, machines, and equipment, material handling equipment; raw materials and product storage facilities.

4. Design and/or improvement of planning and control systems for: Distribution of goods and services, production, inventory, quality, plant maintenance and engineering, or any other function.

5. Development of cost control systems such as budgetary controls, cost analysis, and standard cost systems.

6. Product development.

7. Develop and install wage incentive systems.

8. Development of performance measures and standards (including work measurement and evaluation systems).

9. Job evaluation.

10. Evaluation of reliability and performances.

11. Operations research including such items as mathematical analyses, systems simulation, linear programming, and decision theory.

12. Design and installation of data processing systems.

13. Office systems, procedures and policies.

14. Organizational planning.

15. Plant location surveys which consider potential market for plant, raw material sources, labor supply, financing, and taxes.

These categories are subject to augmentation to keep abreast of the broadening scope of Industrial Engineering. All additions will be subject to review by the Professional Standards Director.

I am confident that each of you will agree that the new categories are a tremendous improvement over those which have been used for several years.

CHANGING SCOPE

The scope of Industrial Engineering, which provides assistance to the Membership Qualifications Committees, needs to be kept abreast of the constant changes taking place in the profession. The material which has been included in the manual for several years is generally limited to manufacturing and does not fully recognize the modern image of Industrial Engineering.

To replace the scope which has been used, the new Membership Qualifications and Classification Manual will include the material which was recently published in the special issue of the *Journal* titled, "The Emerging Role of Industrial Engineering." Rather than repeat this entire article here, may I recommend that you again read the article. The use of this material will greatly assist those who must evaluate applications for membership in the Institute.

The new Membership Qualifications and Classification Manual will be much more complete and comprehensive than the present one. The new manual will include many more specifics to help the chapter qualifications committees and enable them to better understand the criteria used by the Membership Board of Review in evaluating applications which cannot be approved by the Executive Secretary. By bringing about a better understanding and spelling out of how specific credit is given for teaching, for supervisory responsibilities, etc., the taskforce and your President are confident that the percentage of applications which now have to go to the Membership Board of Review for processing will be greatly reduced.

It is my fond hope that each of you now adequately understand the background to vote intelligently on the proposals developed by the taskforce. The decision is now up to you.

If you vote for the changes, it is the feeling of the Board of Trustees, including the senior officers of the Institute that our new membership qualifications will be adequate for many years and will insure continued professional growth of the American Institute of Industrial Engineers.

I am sure you all join me in expressing gratitude and appreciation to E. J. Palisin, W. E. Fourqurean and the members of the New Orleans Chapter who have served on the Membership Board of Review, and the qualifications taskforce. A vote of thanks should also go to the chapter presidents for their significant contributions to the taskforce and to J. L. Schaefer for his work in revising the Membership section in the Constitution.

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RECENT READABLES

AUTOMATION

"To Succeed with Automatic Control—Think Small," A. J. Dolan, FACTORY, *August, 1961.*

Thinking big can be the wrong way to start if you're trying to cut costs with automatic controls. One step-at-a-time improvements using modest-priced controls may pay off faster in the end. *(I. L. Haines, Lukens Steel)*

ENGINEERING ECONOMY

"Effects of Obsolescence on Tax Depreciation Practice," Paul T. Norton, Jr., THE ENGINEERING ECONOMIST, *July-August, 1961.*

Everybody complains about the way obsolescence is handled in tax depreciation practice, but nobody has as yet found a solution that satisfies both the taxpayer and the tax collector. In this short article an attempt is made to discuss several aspects of the problem which the writer believes either have not been fully understood by most persons, or else have not been explained sufficiently by those who advocate certain procedures.

GENERAL

"Assimilating the College Graduate [illegible] to Industry," R. D. Garton, PERSONNEL [illegible], *January-February, 1961.*

The difficult transition from campus to industrial life stems primarily from lack of college preparation for the more prosaic aspects of industry. This transition can be alleviated by the right kind of training and the author gives guidelines for doing so. *(A. L. Friedrichs—Ethyl Corporation)*

"The 'Functionaline' Organization Plan," Harold B. Wilson, THE OFFICE, *July, 1961.*

This concept, which breaks the bounds of departmentalization of functions, is based on the assumption that most office workers can perform different tasks if given the opportunity and training.

"Management and the Productivity of Labor," Robert Zager, [illegible] MANAGEMENT, June, 1961.

The author makes a strong case for looking to the worker to participate with management in the task of integrating individual efforts to meet departmental goals.

"Output Rates Among Machine Operators," JOURNAL OF APPLIED PSYCHOLOGY, *p. 50, February, 1961.*

A study of the relationship of consistency of output of industrial operators to the adequacy of the financial incentives in their work situations. *(A. L. Friedrich, Ethyl Corporation)*

INVENTORY CONTROL

"A Review of Inventory Control Theory, Ralph L. Disney, THE ENGINEERING ECONOMIST, *July-August, 1961.*

In this paper, an attempt is made to review the published literature, from Babcock's first paper to the present.

SYSTEMS AND PROCEDURES

"How to Keep Employee Time, Cost and Job Records," Carl K. Gieringer, THE OFFICE, *August 1, 1961.*

Several practical and economical systems, which are almost foolproof, indicate how and where employees spend their time.

"Production Gets a Crystal Ball That Works," R. W. Christian, FACTORY, *July, 1961.*

A new technique called "'Line of Balance" is now available to monitor progress on production programs. Based on a set of three ingeniously-related charts, this procedure tells you whether your production is up to schedule and, if not, where to look for the trouble spots. *(I. L. Haines, Lukens Steel)*

WORK MEASUREMENT

"Development and Validation of Synthetic Dexterity Tests Based on Elemental Motion Analysis," Donald W. Drewes, JOURNAL OF APPLIED PSYCHOLOGY, *June, 1961.*

A discussion of the methods and results in evaluating dexterity tests for use in personnel selection. The Purdue Elemental Motions Tests (PEMT) which were designed to incorporate many of the motion elements used in MTM are the main topic of discussion.

"What To Do About Troubles With Incentives," E. Walley, FACTORY, *July, 1961.*

Since an effective incentive plan boosts production by 25% or more, it is only good business to maintain it properly. This article presents eight [illegible] that, if followed, should keep your incentive [illegible] a minimum. *(I. L. Haines, Lukens Steel)*

[illegible]

"Handbook of Automation, Computation and Control," Volume 3, Systems and Components, *edited by Eugene M. Grabbe, Simon Ramo, and Dean Wooldridge, John Wiley and Sons, Inc., New York, 1961, $19.75.*

The third of a three volume set that will be of value to the Industrial Engineer. Volume 1 included General Mathematics, Numerical Control, Operations Research, Information Theory and Transmission, and Feedback Control.

Volume 2 includes Computer Terminology, Digital Computer Programming, The Use of Digital Computers and Data Processors, Design of Digital Computers, Design and Application of Analog Computers and Unusual Computer Systems.

The present volume is devoted to Systems Engineering, Manufacturing Process Control, Chemical Process Control Instrumentation, Chemical Process Control Systems, Component Selection, and Design of Components.

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Index to Volume XII

AUTHOR LISTING

Allderige, John M., Comments on "Work Sampling in Engineering Design Department," May-June, 1961, p. 179.

Bailey, Gerald B., Comments on "An Experimental Evaluation of the Validity of Predetermined Manual Time Systems," September-October, 1961, p. 338.

Balk, Walter L., Performance Review—A Method of Controlling Indirect Effort, May-June, 1961, p. 205.

Beach, Dale S., Productivity, Creativeness and Human Relations, September-October, 1961, p. 349.

Bindschedler, André E. (co-author), Optimal Location of New Machines in Existing Plant Layouts, January-February, 1961, p. 41.

[illegible] D. P. (co-author), Assembly Line Balancing Using the Ranked Positional Weight Technique, November-December, 1961, p. 394.

Block, Stanley M., SEMTAR, Automatic Electronic Motion Timer, July-August, 1961, p. 276.

Buffa, Elwood S., Pacing Effects in Production Lines, November-December, 1961, p. 383.

Camp, William E., Recollections of H. L. Gantt, May-June, 1961, p. 217.

Carrabino, Joseph D., The Metamorphosis of Industrial Engineering into Management Engineering—Plea for Change in Name, January-February, 1961, p. 51.

Clark, Charles E., The Optimum Allocation of Resources among the Activities of a Network, January-February, 1961, p. 11.

Connor, Robert J., Hospital Work Sampling with Associated Measures of Production, March-April, 1961, p. 105.

Conway, R. W. (co-author), A Note on the Assignment of Facility Location, January-February, 1961, p. 34.

Conway, Richard W. (co-author), A Queueing Model with State Dependent Service Rate, March-April, 1961, p. 132.

Drui, Albert B., Industrial Research on the Effects of Pace on Work Sampling Results, January-February, 1961, p. 28.

Dzielinski, B. P. (co-author), Simulation of a Hypothetical Multi-Item Production and Inventory System, November-December, 1961, p. 417.

Ekey, David C. (co-author), Inventory Reorder Points for Conditions of Variable Demand and Lead Time, January-February, 1961, p. 32.

Ekey, David C. (co-author), Operational Methodology for Evaluating Physiological Costs, July-August, 1961, p. 243.

English, J. Morley, New Approaches to Economic Comparison for Engineering Projects, November-December, 1961, p. 375.

Fisher, F. P., Speed Up the Solution to Linear Programming Problems, November-December, 1961, p. 412.

Flagle, Charles D., Probability Based Tolerances in Forecasting and Planning, March-April, 1961, p. 97.

Franz, Donald (co-author), New Measurements to Determine the Effect of Task Factors on Body Member Acceleration Patterns, September-October, 1961, p. 317.

Freed, Roy N., Some Legal Aspects of Computer Use in Business and Industry, July-August, 1961, p. 289.

Freed, Roy N., How Computer Specialists Can Help Lawyers, September-October, 1961, p. 324.

Garg, Anand (co-author), The Aircraft Progress Curve—Modified for Design Changes, January-February, 1961, p. 23.

Gavett, J. William, Sampling to Determine Price Break Advantages in "C" Stock Items, November-December, 1961, p. 406.

Geoffrion, Arthur M., The Origin and Significance of Perceptron Theory, November-December, 1961, p. 399.

Gilbreth, Lillian M., As I Remember Him, March-April, 1961, p. 137.

Goode, Henry P. (co-author), Computing Optimum Shrinkage Allowances for Small Order Sizes, January-February, 1961, p. 57.

Hall, Thomas J. (co-author), Operational Methodology for Evaluating Physiological Costs, July-August, 1961, p. 243.

Helgeson, W. B. (co-author), Assembly Line Balancing Using the Ranked Positional Weight Technique, November-December, 1961, p. 394.

Herda, LeRoy F., Industrial Engineering's Role in Planning for and Setting Up a Tape Controlled Facility, September-October, 1961, p. 338.

Herrick, John S., Using Work Simplification in Research, July-August, 1961, p. 263.

Heyne, Jay B., Planning for Research in Management Control Systems—A Suggested Model, July-August, 1961, p. 253.

Heyse, Herbert W., Work Simplification Applied to Occupational Rehabilitation, September-October, 1961, p. 313.

Horowitz, Ira, Estimating Changes in the Research Budget, March-April, 1961, p. 114.

Ireson, W. Grant (co-author), Statistical Tolerance Limits for Determining Process Capability, March-April, 1961, p. 126.

Jericho, Jack F., President's Comments: Acceptance Speech as President of the American Institute of Industrial Engineers, July-August, 1961, p. 299.

Jericho, Jack F., President's Comments: Problem—Information Please!; Solution—Information Place!, September-October, 1961, p. 369.

Jericho, Jack F., President's Comments: Institute Membership Qualifications—Need for a Change?, November-December, 1961, p. 431.

Johnson, H. J. (co-author), Simulation in the Application of Wage Incentives to Multiple Machines, November-December, 1961, p. 428.

Kilbridge, Maurice D., Nonproductive Work as a Factor in the Economic Division of Labor, May-June, 1961, p. 155.

Kilbridge, Maurice D. (co-author), A Heuristic Method of Assembly Line Balancing, July-August, 1961, p. 292.

Kminek, John M., Time Study Without a Stop Watch, March-April, 1961, p. 102.

Krasnow, Howard S., Rate of Return: A Comparison between Accurate and Approximate Methods for the Nonuniform Income Case, November-December, 1961, p. 387.

Lavender, H. Jerry, Jr., The Relationship of Human Engineering to Industrial Engineering Concepts, January-February, 1961, p. 48.

Levy, Alan J., Managerial Economics and Industrial Engineering, January-February, 1961, p. 18.

Llewellyn, R. W., A Game-Information Theoretic Decision Model, May-June, 1961, p. 159.

Manne, A. S. (co-author), Simulation of a Hypothetical Multi-Item Production and Inventory System, November-December 1961, p. 417.

Manning, F. D., Henry Laurence Gantt in Retrospect, May-June, 1961, p. 218.

Maxwell, W. L. (co-author), A Note on the Assignment of Facility Location, January-February, 1961, p. 34.

Maxwell, William L. (co-author), A Queueing Model with State Dependent Service Rate, March-April, 1961, p. 132.

McCarthy, R. H., Industrial Engineering Technologies for the College Curriculum, January-February, 1961, p. 37.

McHose, Andre H., A Quadratic Formulation of the Activity Location Problem, September-October, 1961, p. 334.

Metzger, R. W. (co-author), A Linear Programming Application to Cupola Charging, March-April, 1961, p. 87.

Milliman, Pierce (co-author), The Aircraft Progress Curve—Modified for Design Changes, January-February, 1961, p. 23.

Moore, James M. (co-author), Optimal Location of New Machines in Existing Plant Layouts, January-February, 1961, p. 41.

Moore, James M., To Queue or Not to Queue, March-April, 1961, p. 118.

Moore, James M., Optimal Locations for Multiple Machines, September-October, 1961, p. 307.

Nadler, Gerald, Will a Change in Name Change Industrial Engineering?, May-June, 1961, p. 210.

Nadler, Gerald (co-author), New Measurements to Determine the Effect of Task Factors on Body Member Acceleration Patterns, September-October, 1961, p. 317.

Neely, Frank H., Henry Laurence Gantt, May-June, 1961, p. 213.

Newberry, Thomas L. (co-author), Inventory Reorder Points for Conditions of Variable Demand and Lead Time, January-February, 1961, p. 32.

Newberry, Thomas L. (co-author), Profit Maximization and Industrial Engineering, May-June, 1961, p. 163.

Nichols, D. Edward, A Statistical Analysis of Whole-Dollar Accounting, May-June, 1961, p. 172.

Porter, David B., Henry Laurence Gantt—My Boss, March-April, 1961, p. 138.

Pound, Herbert E., Operating Systems Control by Use of Prime Paper, November-December, 1961, p. 379.

Provost, Robert G., Sr., The Contributions of Henry Laurence Gantt to Scientific Management, January-February, 1961, p. 62.

Rathe, Alex W., President's Comments: Management Control and Industrial Engineering, January-February, 1961, p. 77.

Rathe, Alex W., President's Comments: Industrial Engineering and Science, Part I, March-April, 1961, p. 144.

Rathe, Alex W., President's Comments: Industrial Engineering and Science, Part II, May-June, 1961, p. 229.

Resnikoff, George J. (co-author), Statistical Tolerance Limits for Determining Process Capability, March-April, 1961, p. 126.

Riordan, D. P. (co-author), Work Sampling in an Engineering Design Department, May-June, 1961, p. 175.

Ross, Donald K., Information Content Analysis, July-August, 1961, p. 267.
Saltzman, Sidney (co-author), Computing Optimum Shrinkage Allowances for Small Order Sizes, January-February, 1961, p. 57.
Scheel, Henry Van Riper, Some Recollections of Henry Laurence Gantt, May-June, 1961, p. 220.
Schmidtke, Heinz (co-author), An Experimental Evaluation of the Validity of Predetermined Elemental Time Systems, May-June, 1961, p. 182.
Schwarzbek, R. (co-author), A Linear Programming Application to Cupola Charging, March-April, 1961, p. 87.
Sellie, Clifford, Comments on "An Experimental Evaluation of the Validity of Predetermined Elemental Time Systems," September-October, 1961, p. 330.
Smalley, Harold E. (co-author), Profit Maximization and Industrial Engineering, May-June, 1961, p. 163.
Smith, Barnard E. (co-author), Statistical Tolerance Limits for Determining Process Capability, March-April, 1961, p. 126.
Smith, S. S. (co-author), Simulation in the Application of Wage Incentives to Multiple Machines, November-December, 1961, p. 428.
Smith, William A., Jr., Engineers and Computists, March-April, 1961, p. 94.
Stier, Fritz (co-author), An Experimental Evaluation of the Validity of Predetermined Elemental Time Systems, May-June, 1961, p. 182.
Svenson, Arthur L., Henry Laurence Gantt—Industrial Conservationist, May-June, 1961, p. 222.
Taggart, John B., Comments on "An Experimental Evaluation of the Validity of Predetermined Elemental Time Systems," November-December, 1961, p. 422.
Talbird, Joseph B. (co-author), Inventory Reorder Points for Conditions of Variable Demand and Lead Time, January-February, 1961, p. 32.
Taylor, W. Sidney, System Simplification, January-February, 1961, p. 3.
Thompson, David A., Time Study Sample Size—The Effect of Effort Rating Variation, March-April, 1961, p. 122.
Werner, Charles A., The Supreme Court and Arbitration, July-August, 1961, p. 239.
Wester, Leon (co-author), A Heuristic Method of Assembly Line Balancing, July-August, 1961, p. 292.
Weston, Austin, Summary of the Industrial Engineering Symposium, Northwestern University, November, 1959, March-April, 1961, p. 139.
White, James M., The Use of Learning Curve Theory in Setting Management Goals, November-December, 1961, p. 409.
Wilding-White, C. F. B., Planning Work Sampling Studies for Efficient Sampling and Processing of the Data, September-October, 1961, p. 343.
Williams, Paul F., The Application of Manufacturing Improvement Curves in Multi-Product Industries, March-April, 1961, p. 108.
Wolf, M. (co-author), Work Sampling in an Engineering Design Department, May-June, 1961, p. 175.

TITLES AND SUBJECTS

AIIE

Carrabino, Joseph D., The Metamorphosis of Industrial Engineering into Management Engineering—Plea for Change in Name, January-February, 1961, p. 51.
Jericho, Jack F., President's Comments: Acceptance Speech as President of the American Institute of Industrial Engineers, July-August, 1961, p. 299.
Jericho, Jack F., President's Comments: Problem—Information Please!; Solution—Information Place!, September-October, 1961, p. 369.
Jericho, Jack F., President's Comments: Institute Membership Qualifications—Need for a Change?, November-December, 1961, p. 431.
Nadler, Gerald, Will a Change in Name Change Industrial Engineering?, May-June, 1961, p. 210.
Rathe, Alex W., President's Comments: Management Control and Industrial Engineering, January-February, 1961, p. 77.
Rathe, Alex W., President's Comments: Industrial Engineering and Science, Part I, March-April, 1961, p. 144.
Rathe, Alex W., President's Comments: Industrial Engineering and Science, Part II, May-June, 1961, p. 229.
Weston, Austin, Summary of the Industrial Engineering Symposium, Northwestern University, November, 1959, March-April, 1961, p. 139.

Data Processing

Freed, Roy N., Some Legal Aspects of Computer Use in Business and Industry, July-August, 1961, p. 289.
Freed, Roy N., How Computer Specialists Can Help Lawyers, September-October, 1961, p. 324.
Herda, LeRoy F., Industrial Engineering's Role in Planning for and Setting Up a Tape Controlled Facility, September-October, 1961, p. 338.
Smith, William A., Jr., Engineers and Computists, March-April, 1961, p. 94.

Decision Theory

Horowitz, Ira, Estimating Changes in the Research Budget, March-April, 1961.
Llewellyn, R. W., A Game-Information Theoretic Decision Model, May-June, 1961, p. 159.
Newberry, Thomas L., and Smalley, Harold E., Profit Maximization and Industrial Engineering, May-June, 1961, p. 163.

Economics

Levy, Alan J., Managerial Economics and Industrial Engineering, January-February, 1961, p. 18.
Newberry, Thomas L., and Smalley, Harold E., Profit Maximization and Industrial Engineering, May-June, 1961, p. 163.

Education

McCarthy, R. H., Industrial Engineering Technologies for the College Curriculum, January-February, 1961, p. 37.
Nadler, Gerald, Will a Change in Name Change Industrial Engineering?, May-June, 1961, p. 210.

Engineering Economy

English, J. Morley, New Approaches to Economic Comparison for Engineering Projects, November-December, 1961, p. 375.
Krasnow, Howard S., Rate of Return: A Comparison between Accurate and Approximate Methods for the Nonuniform Income Case, November-December, 1961, p. 387.

Facilities Planning

Bindschedler, André E., and Moore, James M., Optimal Location of New Machines in Existing Plant Layouts, January-February, 1961, p. 41.
Conway, R. W., and Maxwell, W. L., A Note on the Assignment of Facility Location, January-February, 1961, p. 34.
Herda, LeRoy F., Industrial Engineering's Role in Planning for and Setting Up a Tape Controlled Facility, September-October, 1961, p. 338.
McHose, Andre H., A Quadratic Formulation of the Activity Location Problem, September-October, 1961, p. 334.
Moore, James M., Optimal Locations for Multiple Machines, September-October, 1961, p. 307.

Information Theory

Geoffrion, Arthur M., The Origin and Significance of Perceptron Theory, November-December, 1961, p. 399.
Ross, Donald K., Information Content Analysis, July-August, 1961, p. 267.

Inventory Control

Dzielinski, B. P., and Manne, A. S., Simulation of a Hypothetical Multi-Item Production and Inventory Sytem, November-December, 1961, p. 417.
Ekey, David C., Talbird, Joseph B., and Newberry, Thomas L., Inventory Reorder Points for Conditions of Variable Demand and Lead Time, January-February, 1961, p. 32.
Gavett, J. William, Sampling to Determine Price Break Advantages in "C" Stock Items, November-December, 1961, p. 406.

Labor

Werner, Charles A., The Supreme Court and Arbitration, July-August, 1961, p. 239.

Linear Programming

Fisher, F. P., Speed Up the Solution to Linear Programming Problems, November-December, 1961, p. 412.
Metzger, R. W., and Schwarzbek, R., A Linear Programming Application to Cupola Charging, March-April, 1961, p. 87.

Measurement

Allderige, John M., Comments on "Work Sampling in an Engineering Design Department," May-June, 1961, p. 179.
Bailey, Gerald B., Comments on "An Experimental Evaluation of the Validity of Predetermined Elemental Time Systems," September-October, 1961, p. 328.
Block, Stanley M., SEMTAR, Automatic Electronic Motion Timer, July-August, 1961, p. 276.

Connor, Robert J., Hospital Work Sampling with Associated Measures of Production, March-April, 1961, p. 105.
Drui, Albert B., Industrial Research on the Effects of Pace on Work Sampling Results, January-February, 1961, p. 28.
Ekey, David C., and Hall, Thomas J., Operational Methodology for Evaluating Physiological Costs, July-August, 1961, p. 243.
Franz, Donald, and Nadler, Gerald, New Measurements to Determine the Effect of Task Factors on Body Member Acceleration Patterns, September-October, 1961, p. 317.
Kminek, John M., Time Study Without a Stop Watch, March-April, 1961, p. 102.
Riordan, D. P., and Wolf, M., Work Sampling in an Engineering Design Department, May-June, 1961, p. 175.
Schmidtke, Heinz, and Stier, Fritz, An Experimental Evaluation of the Validity of Predetermined Elemental Time Systems, May-June, 1961, p. 182.
Sellie, Clifford, Comments on "An Experimental Evaluation of the Validity of Predetermined Elemental Time Systems," September-October, 1961, p. 330.
Taggard, John B., Comments on "An Experimental Evaluation of the Validity of Predetermined Elemental Time Systems," November-December, 1961, p. 422.
Thompson, David A., Time Study Sample Size—The Effect of Effort Rating Variation, March-April, 1961, p. 122.
Wilding-White, C. F. B., Planning Work Sampling Studies for Efficient Sampling and Processing of the Data, September-October, 1961, p. 343.

Methods

Herda, LeRoy F., Industrial Engineering's Role in Planning for and Setting Up a Tape Controlled Facility, September-October, 1961, p. 338.
Herrick, John S., Using Work Simplification in Research, July-August, 1961, p. 263.
Heyse, Herbert W., Work Simplification Applied to Occupational Rehabilitation, September-October, 1961, p. 313.
Kilbridge, Maurice D., Nonproductive Work as a Factor in the Economic Division of Labor, May-June, 1961, p. 155.
Lavender, H. Jerry, Jr., The Relationship of Human Engineering to Industrial Engineering Concepts, January-February, 1961, p. 48.
Nichols, D. Edward, A Statistical Analysis of Whole-Dollar Accounting, May-June, 1961, p. 172.
Taylor, W. Sidney, System Simplification, January-February, 1961, p. 3.

Motivation and Wage Incentives

Beach, Dale S., Wage Incentives and Human Relations, September-October, 1961, p. 349.
Johnson, H. J., and Smith, S. S., Simulation in the Application of Wage Incentives to Multiple Machines, November-December, 1961, p. 428.
White, James M., The Use of Learning Curve Theory in Setting Management Goals, November-December, 1961, p. 409.
Williams, Paul F., The Application of Manufacturing Improvement Curves in Multi-Product Industries, March-April, 1961, p. 108.

Organization

Heyne, Jay B., Planning for Research in Management Control Systems—A Suggested Model, July-August, 1961, p. 253.

Philosophical and Historical

Camp, William E., Recollections of H. L. Gantt, May-June, 1961, p. 217.
Gilbreth, Lillian M., As I Remember Him, March-April, 1961, p. 137.
Manning, F. D., Henry Laurence Gantt in Retrospect, May-June, 1961, p. 218.
Neely, Frank H., Henry Laurence Gantt, May-June, 1961, p. 219.
Porter, David B., Henry Laurence Gantt—My Boss, March-April, 1961, p. 138.
Provost, Robert G., Sr., The Contributions of Henry Laurence Gantt to Scientific Management, January-February, 1961, p. 62.
Scheel, Henry Van Riper, Some Recollections of Henry Laurence Gantt, May-June, 1961, p. 220.
Smith, William A., Jr., Engineers and Computists, March-April, 1961, p. 94.
Svenson, Arthur L., Henry Laurence Gantt—Industrial Conservationist, May-June, 1961, p. 222.

Planning and Control

Balk, Walter L., Performance Review—A Method of Controlling Indirect Effort, May-June, 1961, p. 205.
Birnie, D. P., and Helgeson, W. B., Assembly Line Balancing Using the Ranked Positional Weight Technique, November-December, 1961, p. 394.
Buffa, Elwood S., Pacing Effects in Production Lines, November-December, 1961, p. 383.
Clark, Charles E., The Optimum Allocation of Resources among the Activities of a Network, January-February, 1961, p. 11.
Dzielinski, B. P., and Manne, A. S., Simulation of a Hypothetical Multi-Item Production and Inventory System, November-December, 1961, p. 417.
Flagle, Charles D., Probability Based Tolerances in Forecasting and Planning, March-April, 1961, p. 97.
Garg, Anand, and Milliman, Pierce, The Aircraft Progress Curve—Modified for Design Changes, January-February, 1961, p. 23.
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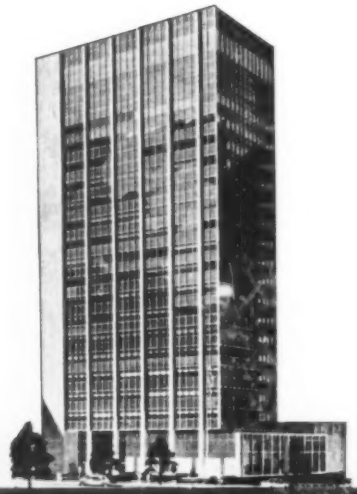

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